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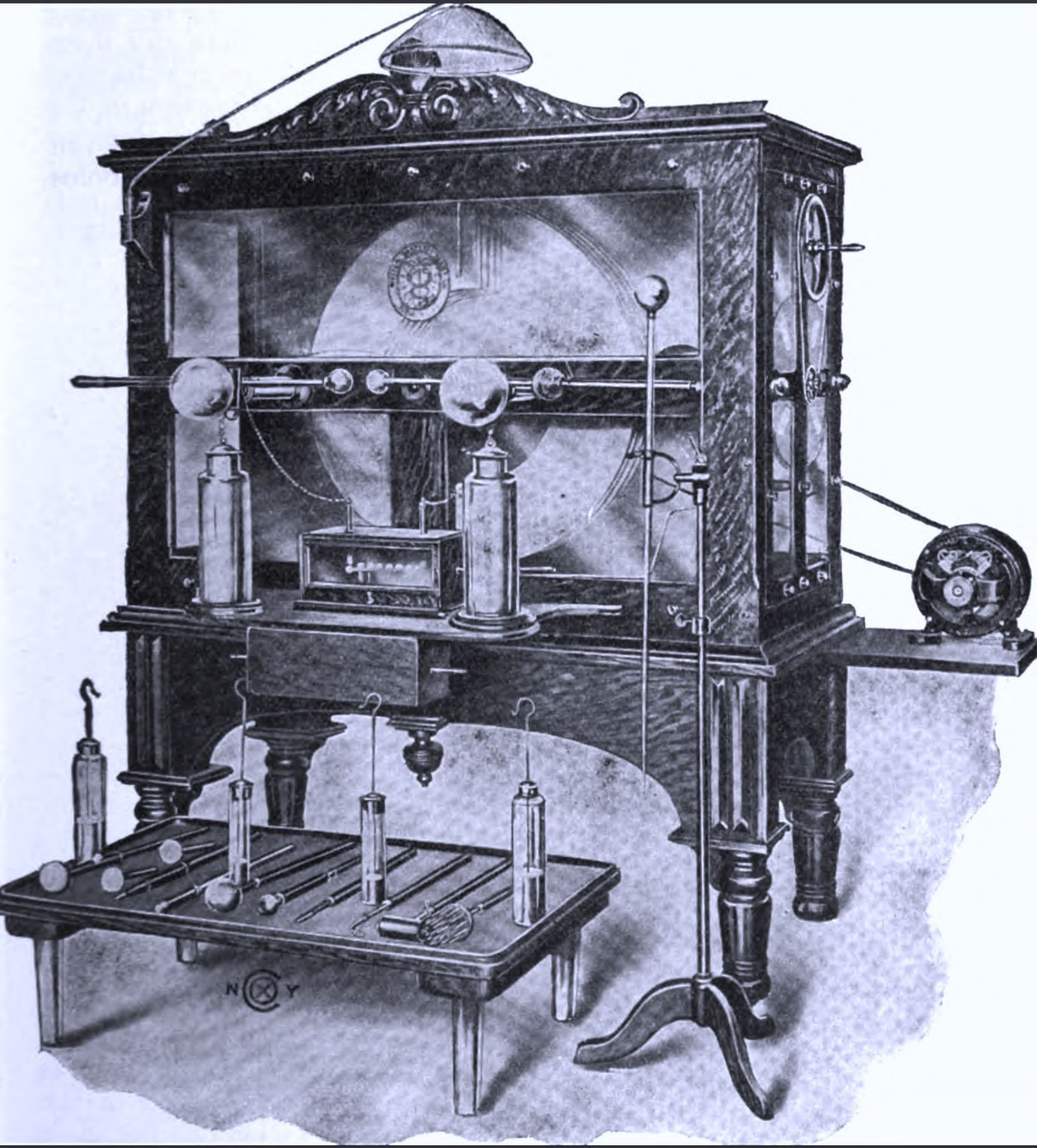

Medical electricity Röntgen rays and radium

Sinclair Tousey

MEDICAL ELECTRICITY
RÖNTGEN RAYS
AND RADIUM

WITH A PRACTICAL CHAPTER ON PHOTOTHERAPY

BY
SINCLAIR TOUSEY, A. M., M. D.
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DEDICATED
TO MY FATHER,
JOHN EUART TOUSEY.

PREFACE TO THE SECOND EDITION

To fulfil its purpose of being useful to those engaged in electrotherapeutics, or having the responsibility of directing treatment by electricity, Röntgen rays, or radium, this work must be revised from time to time. The voluminous literature of this specialty, as well as the author's own experience, afford several advances in general principles, though, of course, it is impossible to include in a single book the many important incidents reported since the appearance of the first edition. Diathermy, sinusoidal currents, radiography with intensifying screens, röntgenotherapy, the Coolidge and similar Röntgen tubes and the author's method of dosage, and radium therapy are noted. The book has been enriched by including several of Machado's tabular classifications of electric methods, effects, and uses. The regrettable death of many of our associates in röntgenology should cause universal observance of the simple precautions which are necessary to ensure the safety of the operator and patient. Too often, however, this warning is disregarded.

SINCLAIR TOUSEY.

NEW YORK CITY, *January*, 1915.

PREFACE

Now that the work approaches completion the author realizes that it is impossible for any book on electricity to be up to date. A weekly magazine would be more apt to justify this title in the case of a science which is developing so rapidly and along such important lines. A systematic attempt to present what has been done and of how to do it may, however, prove useful. Where a statement is ascribed to some particular observer, this is done either because the statement has not yet been verified by universal experience or in order to give due credit to the discoverer of an established fact. The radiographs in this book were made by the author except where otherwise stated, and the technic employed is one available for the average practitioner who desires uniformly successful results. Lightning speed is attainable by the distinguished expert, but sometimes at a ruinous expense for *x*-ray tubes. The author's frequent use of the name "*x*-ray" is perhaps excusable on the ground that it is the name Röntgen gave to the form of radiation which he discovered. The author acknowledges, with thanks, his indebtedness to Dr. Smith Ely Jelliffe and Dr. Harry F. Waite for their assistance; and to his assistants at St. Bartholomew's Clinic and to other gentlemen to whom due credit is given for radiographs made by them. The authors consulted are mentioned at the respective parts of the book, but special mention should be made here of the works of Houston, J. J. Thomson, Curie, Albert-Weil, and Bordier. The author's greatest obligation is, of course, to the professional friends who have referred patients to him.

SINCLAIR TOUSEY.

59 West 46th Street,
New York City.

CONTENTS

MEDICAL ELECTRICITY AND RÖNTGEN RAYS

GENERAL CONSIDERATIONS

MEDICAL electricity, or electro-therapeutics, treats of the application of electricity to the diagnosis and treatment of disease.

Electricity is known to us through the effects produced when an electric charge, electromotive force, or potential is developed, just as the attraction of gravitation is known to us through the effects produced when a body is raised from the ground. Bodies in which an electromotive force or potential or electric charge has been produced are no longer in a state of repose, but tend to produce a variety of effects, one of the simplest and most direct of which is losing their electricity to some other body or to the earth, or, in other words, becoming discharged. Many other effects are produced by the electromotive force in seeking a state of equilibrium—heat, light, the *x*-ray, mechanic motion, chemic changes, physiologic effects. Practically, every one of the effects produced by electric discharges is used in electro therapeutics; and some recapitulation of our knowledge of electric science is necessary to the proper presentation of the special methods of producing and applying electricity in medicine.

Electricity manifests itself in three principal forms, covered by the names of *static*, *voltaic*, and *faradic* electricity. Static electricity is electricity at rest, but tending to a sudden discharge and resumption of electric equilibrium. Voltaic electricity is electricity flowing or tending to flow in a current. Faradic electricity is a derived form of current electricity in which there are rapid alternations of direction and, as applied in medicine, almost always relatively high tension. There are several modifications of these which may be produced by suitable appliances, and among them are Leyden jar discharges and the modern high-frequency current. Then, again, the secondary effects of electricity—heat, light, the *x*-ray, and other radiations—and mechanic motion are valuable applications in many different conditions.

The history of electricity down to about a century ago was the history of static electricity. Thales, one of the seven wise men of Greece, was the first to call attention to the fact that a piece of amber when rubbed would attract light bodies. This was in 600 B. C., but no special importance was attached to the fact. About 300 B. C. Theophrastus recorded the observation that lynthuricum (probably our tourmalin) possessed the same property. This is all the progress that was made in electric science down to the time of Dr. Gilbert, physician to Queen Elizabeth, in 1600. His investigations showed that many substances possessed this property, and those in which it could readily be produced he termed "electrics," from the Greek *elektron*, amber. Among "electrics" are amber, sealing-wax, glass, the diamond, hard rubber, sulphur, resin. Any of these, when rubbed with silk or fur, becomes electrified, and exhibits at once the properties of attracting light bodies which are not charged with electricity, or which are charged with electricity of the opposite sign, + or — (positive or negative), as the case may be; of repelling bodies charged with electricity of the same sign; of inducing an electric charge in neighboring bodies by a process which may be likened to an attraction of the opposite electricity in the other body, and a repulsion of the electricity of the same sign; and of giving sparks or discharging the whole or a part of its electric charge to other bodies brought near enough to it. These sparks are accompanied by sound and a smell of ozone, and sensation and perhaps reflex muscular contraction if applied to the human body. A fine example of the production of electricity by friction is obtained when one walks over a woolen carpet, shuffling his feet, and producing a spark sufficient to light the gas or to give quite a smart sensation if applied to a person.

"Anelectrics" is the name given by Gilbert to the metals and other substances in which he was unable to excite an electric charge by friction. We know now that the reason was that these bodies are good conductors of electricity, and that the charge was carried away as soon as it was produced. A metal or any other good conductor may be charged with electricity by friction, provided it is insulated.

But all substances are not equally charged, and they are not all charged with electricity of the same sign or polarity. Those which would be covered by Gilbert's name, "electrics," develop the greatest amount of electricity when rubbed, and among them the modern hard rubber is perhaps the most active.

From the start, it was noted that glass rubbed with silk, and resin rubbed with cat's fur, became differently charged and attracted each other, while two electrified pieces of glass repelled each other, as did two electrified pieces of resin. To these two different forms of electricity the terms *vitreous* and *resinous* were applied. Later, when it was found that they were complementary, and that two equal charges neutralized each other, the vitreous electricity was called positive, and given the sign plus, while the resinous electricity was called negative, and given the sign minus There is no special reason why either one should be called positive. The names might just as well have been reversed. When two dissimilar bodies are rubbed together, one becomes charged with positive and the other with negative electricity On the two-fluid theory, friction separated the positive and negative fluids, and an excess of one fluid remained in one body, while an excess of the other was formed in the other body. On the one-fluid theory an excess of electric fluid is added to the body which becomes positively charged, and a deficit is produced in the body which becomes negatively charged. The modern ionic theory of electricity will be presented later in connection with the transmission of electricity through gases and liquids. When two members of the following list are rubbed together, the one occurring earlier in the list becomes positively charged, and the one later in the list becomes negatively charged: Fur, wool; ivory, glass; cotton, silk; the hand, wood; sealing-wax, shellac; resin, metals; sulphur, India-rubber; gutta-percha, celluloid.

The attraction of an electrified body for other bodies is illustrated by the motion of a pith-ball suspended near an electrified body, such as the prime conductor of a static machine. The pith-ball immediately swings over in contact with the prime conductor, and as soon as it touches it is again repelled. According to our diagram (Fig. 1), the positive electricity in the prime conductor attracts the negative electricity in the pith-ball and repels its positive electricity. When the pith-ball comes in contact with the prime conductor, its negative charge enters into the prime conductor and neutralizes a portion of the positive charge therein. The pith-ball, being then entirely charged with positive electricity, is repelled by the prime conductor. In Fig. 2 the pith-ball is represented as being suspended between the two prime conductors charged with electricity. It then swings alternately to one and the other, becoming charged at the first contact with positive electricity, and then being attracted by the negative pole, where it loses its positive charge, and, acquiring a negative charge, is again repelled by the negative pole and attracted by the positive. The same repulsion of two similarly charged bodies forms the basis of the instrument called the electroscope.

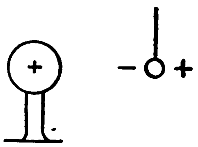

Fig. 1.—Pith-ball attracted by an electrified body.

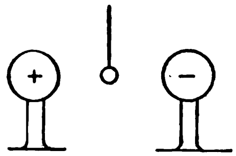

Fig. 2.—Pith-ball swinging back and forth between the two oppositely charged bodies.

The **electroscope** (Fig. 3) consists of a glass case in which a brass rod terminates below in two pieces of gold-leaf, and above in a brass knob. On bringing the brass knob near a positively charged body, negative electricity is attracted into the knob, the positive charge being repelled into the two pieces of gold-leaf, which thereupon become widely separated. On removing the electroscope from the neighborhood of the prime conductor the gold-leaves again fall together, but if the glass knob had been touched to the prime conductor, or had received a spark from it, the whole electroscope would have become positively charged, and the pieces of gold-leaf would have remained divergent until the charge had been lost by contact with some conducting substance.

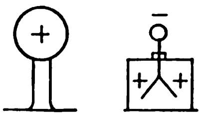

Fig. 3.—Principle of the electroscope.

Fig. 4.—The principle of Wolff's electroscope.

In a new electroscope[1] the gold-leaves are replaced by two quartz filaments coated with platinum. The filaments are fastened to a

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[1] Th. Wulff, Physik. Zeit., April 15, 1907.

conducting rod at the top, and are also joined together at the bottom, where there is a light weight, producing a uniform tension. An electric charge causes the filaments to diverge most widely at their middle points (Fig. 4). The amount of this divergence is observed by a microscope magnifying 70 times. The objective of this microscope is of low, and the eye-piece of high, power. In this way the objective may be at a convenient distance from the filaments.

Another example of the repulsion between bodies charged with the same polarity is seen when one's hair stands on end under treatment by static electricity. The discharge of static electricity produces a spark, with a development of noise, light, heat, and chemical effects. Muscular contraction and sensation may also be produced.

An early type of static electric machine consisted of a cylinder of glass, which, as it revolved, was rubbed by fur or silk, and thus became charged with electricity. At another part of its revolution this electric charge was carried off by metallic combs, which were so near that the electricity could leap across to them from the glass. The combs were connected with a metallic ball, both being insulated, and the rubbers were connected with another metallic ball. These two formed the poles or prime conductors of the machine. The whole would produce a very small amount of electricity, but enough to produce the characteristic effects of static electricity.

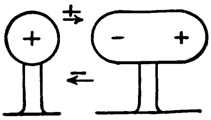

Fig. 5.—Charge by conduction.

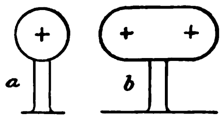

Fig. 6.—Charge by conduction remains permanent in an insulated body after removal from the charging body.

A body charged with static electricity may produce a charge in another body, first, by conduction or convection; second, by a spark discharged; third, by induction. The charge produced in the prime conductors of the old static machines illustrates one and two, the combs becoming charged by a spark discharged from the glass, and the prime conductors receiving their charge by conduction from the combs. Figs. 5 and 6 show what takes place when a body is charged by either conduction or spark from a body already charged. *a* may be the positive pole of a static machine, and *b*, an insulated metallic object. The process is twofold. There is an attraction of the negative electricity in *b* to *a*, and a passage of a part of the positive electricity in *a* into *b*. The result is that *b* becomes charged with positive electricity and remains so after removal from the neighborhood of *a*. The positive charge on *a* is partially neutralized, but if *a* is the positive pole of a static machine, this deficiency is immediately supplied.

A charge by induction is shown by the experiment of bringing an insulated body *b* in the diagram (Fig. 7) near the prime conductor *a*, which in this case is supposed to be positively charged. The negative electricity in *b* is attracted to the surface nearest *a*, while the positive electricity in *b* is repelled to the surface farthest away. Under these conditions the farther extremity of *b* will exhibit the characteristic effects of a body charged with positive electricity. It will attract a negatively charged pith-ball, for instance, but if it is now removed from the neighborhood of *a*, its electric charge would again become neutral. But if *b* were touched by a conductor, *c*, at any time while under the influence of the positive charge in *a*, its positive charge would be repelled into the conductor, and an additional negative charge would be attracted (Fig. 8) from the conductor. The latter may then be removed, and if, now, the insulated body, *b*, which is completely charged with negative electricity, be carried to a distance from *a* by means of its insulated support (Fig. 9), it will be found to still retain its negative electric charge.

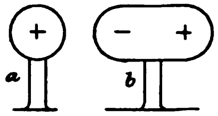

Fig. 7.—Charge by induction. A neutral charge is disintegrated. Electricity of the opposite sign is attracted and of the same sign repelled.

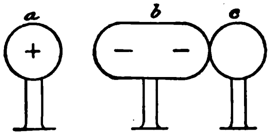

Fig. 8.—Charge by induction completed by contact with a conductor.

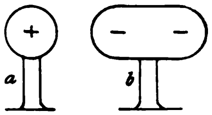

Fig. 9.—Charge by induction remains permanent in an insulated body after removal of the conduction in Fig. 8.

In another experiment (Figs. 10 and 11) two bodies, *d* and *e*, closely in contact with each other, are brought near a positively charged body, *c*; their entire charge of negative electricity is attracted into *d*, which is nearest *c*, and the entire positive charge would be carried into *e*, farthest away. If, now, the two bodies, *d* and *e*, are separated, it will be found that all parts of *d* are negatively charged, and all parts of *e* positively charged, and that these charges will remain permanent even if they are removed to a distance from each other, and from the body *c*, from which the charge was originally induced.

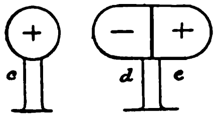

Fig. 10.—Charge by induction in two insulated bodies in contact with each other.

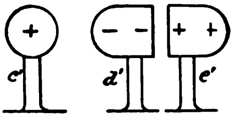

Fig. 11.—Permanent charge in two insulated bodies which are separated while still under inductive influence.

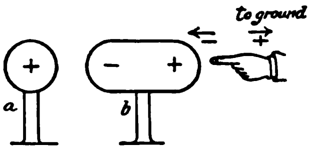

Fig. 12.—Induction in a grounded body.

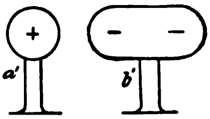

Fig. 13.—Permanent charge in an insulated body if ground connection is broken while still under inductive influence.

A somewhat similar effect is produced (Figs. 12 and 13) if *b* is grounded or connected with the earth while under the influence of *a*, and this ground connection is broken, while *b* is still near *a*. In this case the entire positive charge of *b* is driven to the earth, and *b* becomes completely charged with negative electricity. This charge remains even after *b* is removed from the neighborhood of *a*. The same effect is produced (Figs. 14 and 15) if a negatively charged body is brought in contact with *b* and removed from it while *b* is still under the influence of *a*.

All modern static machines, called *influence machines*, depend on these principles.

Two bodies, *b* and *c*, separated by a sufficient air-space or by some other dielectric (Fig. 16), may be influenced, the one by *a*, positively charged, and the other by *d*, negatively charged, *a* being brought in contact with *b*, and *d* with *c*, *b* becomes completely charged with positive electricity by conduction from *a*, and *c* with negative electricity by conduction from *d*. Both are given a much heavier charge than would otherwise be the case in consequence of the attraction of the two opposite charges of electricity for each other exerted across the space between *b* and *c*. A greater amount of electricity enters *b* from the positive pole, *a*, in consequence of this attraction, and similarly in the case of *c*. The Leyden jar and various other types of condenser depend upon this principle.

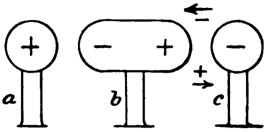

Fig. 14.—Charge by induction completed by contact with a body having the opposite polarity from the inducing charge.

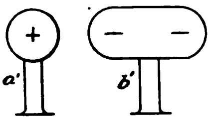

Fig. 15.—Permanence of induced charge after removal of oppositely charged body in Fig. 14.

An electrified body may part with its charge, first, by removal from the neighborhood of the inducing body; second, by conduction through conductors to the earth or some oppositely charged body; third, by convection; fourth, by spark or disruptive charge. One and two have already been sufficiently discussed. Three: when a body is electrified, its charge has a tendency to accumulate wherever it has sharp points, and when any other body is brought sufficiently close, a silent discharge takes place between the two, accompanied by a faint violet light, visible both on the points of the electrified body and on the surface of the body to which the discharge passes. Such a discharge is known as the *static breeze*, or, in talking of high-frequency currents, as the *effluve*. It can be seen in a darkened room whenever an electrified body, like one pole of a static machine or a charged wire, presents a point or is moderately near, but not within sparking distance, to the other pole or some other body. With extremely high charges of electricity this same convective discharge from points on the charged body can be seen to take place, even if no other body is anywhere near. This constitutes the phenomenon called *St. Elmo's fire*, sometimes occurring on the top of the masts of ships.

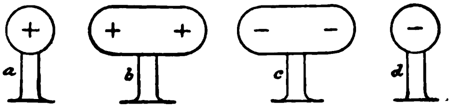

Fig. 16.—Principle of a condenser charge.

STATIC ELECTRICITY

INSULATORS AND CONDUCTORS

THE reason why a metal ball upon a glass standard retains its charge of electricity is because glass is an insulator, or a non-conductor of electricity. The terms *conductor* and *non-conductor* are relative. Conductors permit the passage of electricity readily, *i. e.*, with little resistance. Non-conductors transmit electricity very poorly, or with great resistance. Glass and air are very poor conductors of electricity, and an electrified body will, if insulated by either of these two, lose its charge very slowly under ordinary conditions. Air may become a good conductor in several different ways, one of the most interesting being by ionization of the air under the influence of the *x*-ray. The discharge of an electroscope and the falling together of its leaves under ionization of the air by the *x*-ray have been proposed as a quantitative measure of the latter.

Among the conductors are metals, charcoal, graphite, acids, water, and the human body. Among partial conductors are linen, cotton, alcohol, ether, dry wood, and paper. Among non-conductors are oils, porcelain, silk, resin, gutta-percha, shellac, hard rubber, paraffin, glass, and air.

An electric charge passes through a conductor easily and quietly, unless the conductor forms too small a path for the quantity of electricity passing through it. In such a case the conductor becomes hot. In the case of a non-conductor, practically no flow is permitted unless the pressure or tension is very great, and then the electricity does not pass by conduction, but by a disruptive discharge. It seems to break through the non-conductor, and in the case of violent discharges of electricity, as in lightning, the effect upon non-conductors is most destructive. Conductors are used for the passage of electric charges and currents. Non-conductors or insulators are used to protect the charged conductors from contact with other conductors, and thus to retain their electricity.

For all practical purposes the earth may be regarded as an inexhaustible storehouse of both positive and negative electricity. In a static machine a charge communicated to both poles is much increased if one of them is grounded or connected with the earth. When two perfectly insulated dissimilar bodies are rubbed together, a negative charge will be produced in one and a positive charge in the other, by a process which may be regarded as a disintegration of a normal neutral charge in both into positive and negative charges, all the positive electricity of both being accumulated in one body and all the negative in the other. If, now, one of these bodies, say the negative one, is grounded, an additional amount of negative electricity enters it from the earth, attracted into the negative pole by the positive charge in the other pole, and then with a stronger negative pole a stronger positive charge is produced in the other by induction. This is assuming, of course, that the process of friction is going on while this ground connection is made.

It appears to be universally true that the development of the positive charge of electricity of any form whatsoever is attended by the development of an equal negative charge. An electric charge exerts a force—its *electromotive force*—tending to produce again a neutral state. In the case of static electricity, the charge is altogether on the surface of the electrified body. This may be due to the repulsion which an electric charge exerts upon electricity of the same sign, either positive or negative, and the tension or pressure of static electricity is so great that this repulsion repels practically the entire charge to the surface.

Static electricity must be considered separately from dynamic electricity because it is only by the so-called static machine that such very high voltages can be directly and readily obtained. The very existence of a useful charge of static electricity requires that the charged body shall have both capacity and insulation. The difference between electricity in the form of a current and electricity stored up as a static charge is comparable to the difference between water poured through an open ring and water poured into a cup. "A cupful of water" implies that the cup is closed at the bottom, and "a charge of static electricity" implies that the charged body is capable of retaining the charge. Useful charges of static electricity are of such high voltages that the requisite degree of insulation can be conveniently obtained only by means of apparatus dependent upon the excitation of non-conducting plates of glass, hard rubber, paper, or mica.

THE LEYDEN JAR

A glass jar, coated on the outside and on the inside with tin-foil to about half its height, and with a brass rod fastened to the cork and connected with the inner coat by means of a loose chain, the brass rod terminating above in a knob, constitutes the apparatus known as the Leyden jar. To charge it, the knob on the upper end of the rod is brought near enough to one pole of the static machine to receive a charge by conduction, convection, or by spark (Fig. 17), while at the same time the outer coat of tin-foil is grounded by holding the jar in the hand. The inner coat becomes fully charged with positive electricity if it is the positive pole of the static machine which is used, and the outer coat, separated from it by only the eighth of an inch thickness of the glass, becomes negatively charged by induction. This negative charge of the outer coat is attracted into it from the ground. The two charges are a very great deal stronger than either would be alone, in consequence of the attraction of the two for each other, and the consequent condensation of electricity. Such a charged Leyden jar will retain its charge for a long time in spite of the fact that it is carried about and handled by the outer coating, or, if it is set down on a glass plate or some other insulator, the knob connected with the inner coating may be touched without any discharge occurring. Touching both the outer coating and the knob connected with the inner coating at the

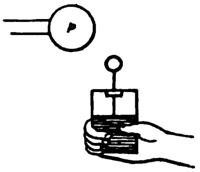

Fig. 17.—Charging a Leyden jar.

same time will produce a discharge, which, in the case of a Leyden jar of any size, occurs as a very brilliant, white, large spark.

Such a discharge produces physiologic effects, the most manifest of which, with a small jar, being a single muscular contraction of the forearm, but, extending, with a large jar, to the muscles of the arm and even to the chest. A very large Leyden jar gives a powerful shock, and so does a battery of Leyden jars with their outer coatings all connected with one terminal and the inner coatings with another. The violence of a discharge will depend upon the area of lead-foil in the Leyden jar or jars, and the tension of the charge. A whole group of people may receive a shock at one time if they join hands in a ring, and the outer coat of a large Leyden jar be grasped by one person, and the person at the other end touches its inner rod. Experimentally, a whole regiment of soldiers have been given a simultaneous shock in this way.

To avoid disagreeable shocks, Leyden jars should never be left in a charged condition, but should be discharged by a special curved metal rod with an insulated handle made for this purpose.

Leyden jars form an important part of the apparatus for treatment by static electricity and by the modern high-frequency currents.

If a Leyden jar consists of a glass tumbler with a loose inner coating in cup shape, and an outer one of the same nature and is charged in the ordinary way, the inner metal coating may be taken out and handled, and will be found not to possess any electric charge. The outer coat may then be removed, and will be found to have no charge. The entire charge remains upon the two surfaces of the dielectric, the glass, and on reassembling the parts of this dissected Leyden jar, it may be discharged in the ordinary way.

The other type of condenser, consisting of some dielectric sheets of mica or paper, between which are sheets of a conductor, like tinfoil, are used where a very large surface is required, and where the tension is comparatively small. Such condensers will be described in greater detail in connection with induction coils.

NATURE OF ELECTRIC SPARKS

The discharge occurring between the two poles of a static machine varies in accordance with their distance apart. If they are very close together, there is an electric arc; if a little further apart, there is an almost continuous thread of white light. Separating the poles an inch or two, the discharge changes to a thread, or a number of threads, of violet light, with brilliant white sparks at each pole. If a bit of wood, like a match, is held close to the positive pole, the spark will be deflected toward the wood, but little or no effect is produced by wood held near the negative pole. If a pointed metal electrode connected with the earth is held anywhere near the positive pole, a bright violet light, like a star, appears upon the point, and when it is brought almost in contact with the positive pole, a bright white continuous thread discharge takes place. When the same grounded point electrode is brought near the negative pole, the star does not appear until the point is within a few inches of the pole, and when it is brought still nearer, a violet brush discharge takes place from the point to the negative pole.

The discharge occurring between the two poles of a static machine, when they are separated by a considerable distance, is best seen in a darkened room. The whole space between the two poles is filled by an elliptic mass of violet light. From the positive pole there shoot off simultaneously perhaps a dozen zigzag threads of violet light, giving an appearance likened to a fox's tail, while the discharge from the negative pole is simply a diffused effluve of violet light. Connecting the inner coat of one Leyden jar with the positive, and the inner coat of another Leyden jar with the negative, pole, and connecting their outer coats together or both to the earth, the discharge between the poles of a static machine ceases to be a continuous one, and becomes a succession of brilliant large white sparks. These sparks are exactly the same as the spark produced by the discharge of a Leyden jar. In the diagram (Fig. 18) *p* is the positive and *n* the negative pole of a static machine. As the electric charge is produced by the operation of the machine, the inner coat of the Leyden jar, *l*, is positively charged, and the negative electricity in the outer coats of both jars, connected by a brass rod, is attracted to the outer coat of *l*, and this strong negative charge of its outer coat increases still more the capacity of the inner coat for positive electricity. The same process takes place in the Leyden jar, *l*, whose inner coat receives a very heavy negative charge, and whose outer coat receives the entire positive charge of both jars. When the machine is turned on, it is noted that the usual brush or spark discharge does not take place across the space between the poles of the machine. The charge is being stored up in the two Leyden jars, and in each one is bound by the attraction existing between the positive and negative charges, separated only by the thickness of a sheet of glass. Eventually, the Leyden jars become overcharged and a discharge occurs. A brilliant white flash passes across the space between the poles of the machine, forming a continuous zigzag line. At the same time a crown of zigzag, violet, thread-like flashes starts upward from the upper edge of the outer coat of each Leyden jar. The inner coats have parted with their excessive charge, partly by discharge from the innner coat of one Leyden jar to that of the oppositely charged one, through the medium of the poles of the machine and the intervening air-space, and partly by discharge from the outer to the inner coat of the same jar over the surface of the glass. The latter, in each jar, is a consequence of the discharge of the inner coat, which leaves an excess of charge on the outer coat no longer bound by the attraction of the internal charge. A similar excess of charge of the opposite sign is liberated at the same time on the outer surface of both Leyden jars and part of these two opposite charges are exchanged and neutralized through the brass connecting rod. The rod, although large enough to carry many thousand times that amount of electricity in a quiet current, where only its ohmic resistance would be operative, develops an enormous inductive impedence to the passage of such a discharge as occurs in this case. This is why some of the discharge can be seen passing from the outer to the inner coatings of the surface of the glass.

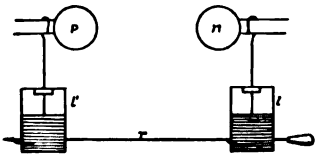

Fig. 18.—Leyden jars causing separate powerful sparks between the poles of a static machine.

The resistance of the latter path is great, but a portion of a discharge simply cannot get through the brass rod, and has to leap across the space described. Leyden jar discharges modified by inductive impedence in coils and the like form the modern high-frequency apparatus. If the poles of the static machine are too widely separated, no discharge will occur. The Leyden jars will simply hang there in a fully charged condition, and in the dark, of course, a convective discharge can be seen leaking into the air from all points or rough places in the poles or jars. When the poles are brought nearer together, the flashes again take place, and are at first loud and brilliant, and at long intervals—perhaps only fifteen in a minute. As the poles are brought nearer and nearer, the flashes become less brilliant and more frequent, and at a distance of half an inch or an inch they form a continuous stream of white light with a very rapid succession of reports, which are not as deafening as when the distance was greater. If a static machine has been running with the poles so wide apart that no discharge occurs, and is then stopped, the Leyden jars still remain charged, and a flash will occur on pushing the poles toward each other.

When a Leyden jar is discharged by placing one end of an insulated metal rod in contact with the outer coat and bringing the other end near the knob connected with the inner coat, the spark which is produced does not completely discharge the jar, and after a minute or two a smaller spark or residual discharge may be obtained in the same way.

The electric spark produced by the discharge of a Leyden jar or any other condenser appears like a single flash, lasting quite an appreciable length of time. Experiments in which the spark is observed by means of rapidly revolving mirrors do not show the reflection of the spark as a bright spot, which would be the case if the discharge were instantaneous. On the contrary, the image appears drawn out into a line, and measurements which have been made indicate that a Leyden jar discharge, between brass knobs five millimeters or one-fifth of an inch apart, lasts about one-twenty-four-thousandth of a second. The same kind of experiment upon a long spark shows that it begins simultaneously at both poles, and is visible later in the middle. Static electricity travels through the air and through most metallic conductors at the rate of 188,000 miles a second, so that the difference in time between the appearance of luminosity at the middle of the path of the spark and at the two ends is very small indeed. The discharge takes a zigzag course, just exactly as is the case with the lightning flash, because of the varying resistance caused by the condensation of the air before it in different parts of its path. A spark passing through a partial vacuum forms practically a straight line.

Oscillatory Nature of Spark Discharges.—A single spark produced by a Leyden jar represents millions of to-and-fro discharges, and even the lightning flash across a mile or more space represents 300,000 oscillations. Two oppositely but equally charged bodies (Fig. 19), between which a pith-ball is suspended, will lose their charge, and both become neutral in consequence of oscillations of the pith-ball, which may first touch *p*, and taking away a part of the positive charge, is repelled by *p* and attracted to *n*, where it gives up its positive charge, neutralizing part of the negative charge of *n*. Another part of this negative charge is communicated to the pith-ball and carried across to *p*. The neutralization of a Leyden jar charge is accomplished by a somewhat analogous series of oscillations. It is the enormously high frequency of these oscillations, millions a second, that gives the name to "high-frequency" currents. This subject will be dwelt upon in another chapter.

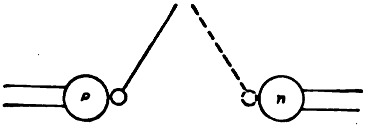

Fig. 19.—Pith-ball oscillating between two oppositely charged bodies and discharging them.

Any electric spark in the open air produces *discharge rays*, which are described elsewhere and have some of the properties of the *x*-ray.

The Electrophorus.—If a mass of melted resin is poured into a metal plate and allowed to cool, it may be charged with negative electricity by rubbing it with cat's fur. If a metal disk, somewhat smaller than the resin, is placed upon its surface, the neutral charge of the metal disk becomes separated into a positive charge, induced on its lower surface, and a negative charge, on its upper surface. While the disk is in this condition, if it is touched by the finger or some other grounded conductor, its negative charge will be removed, and an addition made to its positive charge (Fig. 20). The negative charge on the resin is not communicated to the metal disk because the rough and uneven surface of the resin prevents contact except at a comparatively few scattered points. The resin is so poor a conductor that its charge remains fixed on the different parts of its surface which do not come directly in contact with the metal disk. The negative charge on the resin attracts a comparatively great charge of positive electricity into the disk placed on its surface and connected with the ground. The positive charge on the disk in turn exerts an induction upon the resin, increasing its negative charge by attracting negative electricity from the earth through the outer metal plate, containing the resin, and which had better not be insulated. The finger, or other ground connection, is to be removed while the disk is still in position. The disk is then removed by means of its glass handle, and will be found to have quite a charge of positive electricity. This may be used to give a spark, as in the diagram (Fig. 21), or to charge a Leyden jar. A long succession of positive charges may thus be induced in the metal disk, and used to charge a large Leyden jar, all being obtained from the original single charge of negative electricity produced upon the resin by friction. This principle is the foundation of the modern static or influence machine.

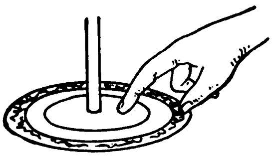

Fig. 20.—Charging the electrophorus.

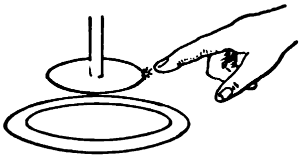

Fig. 21.—Spark from the electrophorus.

THE MODERN STATIC OR INFLUENCE MACHINES

The amount of electricity which can be obtained by friction is so small compared with the amount of work required to produce it that the apparatus dependent upon this principle is impracticable, but a small charge of static electricity originally produced by friction may be so increased by means of a suitable induction apparatus as to be powerful enough for every medical purpose.

In the static machine of the simple friction type a positive charge is produced upon a revolving glass plate by friction. This positive charge is carried by the glass to the place where the metal collecting comb of one of the poles is near the plate (Fig. 22). The positive charge upon the plate separates the neutral charge of the comb and prime conductor, inducing a negative charge in the comb and a positive charge in the pole (Fig. 23). The negative charge escapes from the points of the comb as a static breeze or brush discharge, which, passing to the surface of the plate, neutralizes the positive charge there and leaves the plate ready to be recharged by friction at another part of its revolution. The rubber, of course, is negatively charged, and is connected with the other pole of the machine.

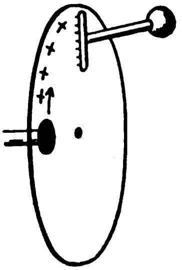

Fig. 22.—Principle of the static machine of simple friction type.

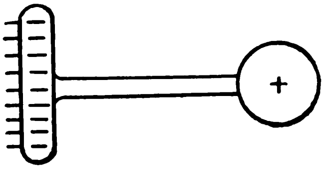

Fig. 23.—The charge in the comb of a static machine.

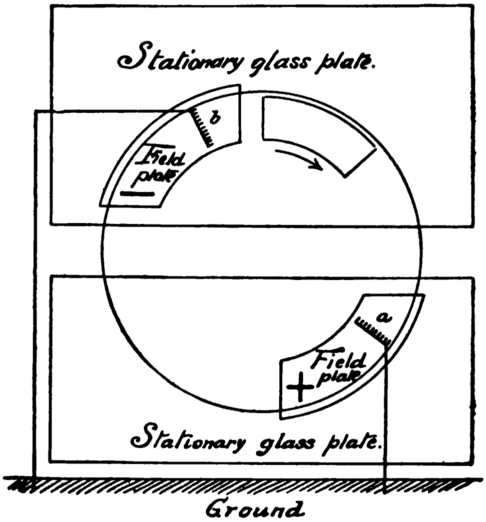

Fig. 24.—Diagram of influence type of static machine.

In one type of influence machine there are two field-plates of paper or of metal foil pasted upon two separate stationary glass plates (Fig. 24). These field-plates are slightly charged—*a*, with positive and *b*, with negative electricity. A third insulated piece of paper or metal called a carrier is fastened upon a revolving glass plate. This carrier is grounded or connected with the earth when it is opposite *a*, and, like the metal disk of an electrophorus, will have a small charge of free electricity after it has moved past *a*. When it has made part of a revolution, a collecting brush comes in contact with the negatively charged carrier. This collecting brush is connected with the negative field plate *b*, to whose original small charge is added the major part of the charge brought by the carrier, which in this way becomes less fully charged. Continuing its revolution the carrier comes opposite the negative field plate *b*, with which it is no longer in connection, while, on the other hand, it is again grounded. Under the influence of a somewhat increased negative charge of *b* a somewhat stronger positive charge is induced in the carrier—positive electricity being attracted into it from the earth, and negative electricity being repelled from it to the earth. While the carrier is opposite *b*, this positive charge is bound or fixed upon the carrier by the attraction of the oppositely charged field plate, just as is the case with the charge upon the two coats of a Leyden jar. After it has revolved past *b* and is also no longer grounded, the positive charge upon the carrier becomes free and is carried by a collecting brush, which comes in contact with it to *a*, strengthening the positive charge already present in that field-plate. With a rapid rotation and a mechanic construction which permits of very little leakage of electricity by conduction, the field-plates soon acquire a very powerful charge.

From the beginning a carrier, when negatively charged, gives up only a certain portion of its charge to the collecting brush, leading to the negative field-plate, so that both the carrier and the field-plate have the same charge in proportion to their size. The unappropriated negative charge upon the carrier is taken up by the combs of the prime conductor before the carrier reaches the part of its revolution, where it again comes under an inductive influence. This charges the negative pole, and the positive pole receives its charge in the same way, through a comb applied at the opposite part of the carrier's revolution. The two poles are the places at which the two opposite charges are nearest together, and where they exert their greatest attraction for each other, and where a discharge occurs when sufficient tension is produced to overcome the resistance of the intervening air-space. The attraction of the charge in the opposite pole is a special factor in the passage of the unappropriated charge from the carrier to the comb of the prime conductor. In this transfer from carrier to prime conductor the process may be regarded as one of induction, just as is the case in the simple friction machine. Instead of making a ground connection when the carrier is opposite one of the field-plates, it is customary in static machines which have more than one carrier to have the connection made between the two oppositely charged carriers by a pair of neutralizing brushes joined by a brass rod. One carrier has attracted into it the positive charge of both, while at the same time the negative charge of both is attracted to the other carrier.

The **Toepler machine** is constructed on the principle indicated above. A machine shown in Fig. 25 is one placed inside the glass case of the Holtz machine, to which it gives the initial charge. In this particular Toepler machine there is a stationary glass plate, twelve inches in diameter, upon the back of which are pasted the field-plates, two pieces of paper forming curved strips about two inches wide, with their outer edge about an inch internal to the outer edge of the stationary plate. Each of these strips occupies about one-fourth of the circumference of a circle. A strip of sheet metal is pasted directly upon the glass along the center of each strip of paper, the sheet metal forming a strip about half an inch wide and five inches long, with somewhat larger extremities. The revolving glass plate is about an inch and a half less in diameter than the stationary one, and is at a very small distance from it. Upon its front surface, that is, the surface away from the stationary plate, there are pasted eight carriers—strips of metal about three-fourths of an inch wide and two inches long, arranged in the direction of the spokes of a wheel. As this plate revolves these metal carriers are rubbed by four different wire brushes; two of these are neutralizing brushes, the other two appropriating brushes connected with the two field-plates. There are two combs not shown in the picture for collecting the unappropriated charge from each carrier, and leading it to the field-plates of the Holtz machine. This Toepler machine is operated by hand, and a few turns of it generate a sufficient charge to enable the Holtz machine to start up promptly. The Toepler machine, it will be seen, is self-charging; the friction of the brushes upon the metal carriers and also upon the glass surface produces sufficient electricity to start it, and this is rapidly multiplied by the induction which characterizes every form of influence machine.

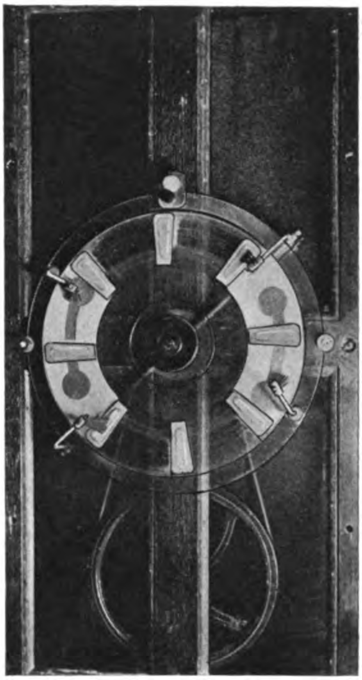

Fig. 25.—Toepler machine used to excite a Holtz machine.

All these modern types of static machine are capable of producing very powerful charges when a number of large plates are used, a high rate of speed is produced by electric motors, and the glass cases in which they are contained are air-tight, and the machines are kept free from dust and moisture. The large powerful machines so commonly used in America are capable of producing very much better results as a therapeutic agent and for the operation of an x-ray tube than the smaller machines, usually made in Europe, which can be lifted by hand and are hardly more than laboratory toys.

The **Wimshurst machine** (Fig. 26), in its simplest form, consists of two glass plates of equal size, and very close to each other, revolving in opposite directions. Each has a number of metal carriers pasted upon it, and these also serve the purpose of field-plates, and are on the side away from the other plate. Each plate has its own pair of neutralizing brushes, connected by a brass rod. There is a double collecting comb passing from each prime conductor to the two glass plates. The comb from the negative pole is forked and extends close to the surface of both plates and receives its charge a carrier on each of the two plates simultaneously. There are no special field-plates and no appropriating brushes, bringing a charge directly from the carrier on one plate to any part of the other plate. The initial charge is produced by the friction of the neutralizing brushes upon the glass plates and metal carriers As soon as any of the carriers become charged, they act upon those of the other plate by induction, in the way described as taking place in the Toepler machine; and very soon a powerful charge is generated and may be seen passing across the space between the discharging rods connected with the two poles (Fig. 27). Like the Toepler machine, this is self-exciting, and is often employed to give the initial charge to a Holtz machine. For this purpose it is placed inside the glass case of the larger machine and given a few turns by hand.

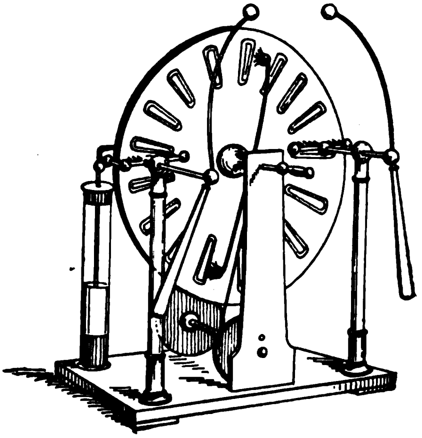

Fig. 26.—The Wimshurst machine.

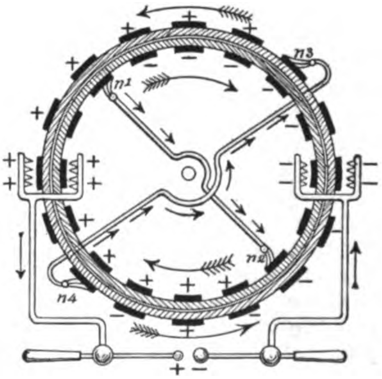

Fig. 27.—Principle of the Wimshurst machine (King).

The Holtz Machine (Fig. 28).—In this variety of influence machine there are two large fixed field-plates and a plain revolving glass plate without carriers (Fig. 29). There are a pair of combs at opposite ends of a metal rod, performing the office of neutralizing brushes, and there are collecting combs from the prime conductors. It is necessary to supply an initial charge, and formerly this was done by means of a piece of hard rubber excited by friction and held against one field-plate while the glass plate revolved. It is customary now to have a small Toepler or Wimshurst machine inside the same case to produce the initial charge. A modern Holtz machine is made up of several couples of revolving and stationary plates, usually placed in a series upon the same axle, and turned by an electric or water motor. In the diagram only a single couple is represented. The stationary glass plate is in two separate portions, *a*, *b*, *c*, *d*, and *e*, *f*, *g*, *h*, which are secured to the wooden case of the machine by wooden and hard-rubber clamps which completely insulate them. They do not come in contact with any other part of the machine. The field-plates are two large pieces of paper with a half-circle of sheet metal covering the paper at one end, and turning over the edge of the glass at the edge where the revolving glass-plate first meets the field-plate. The field-plates are on the front of the divided stationary glass plate, and so are the semicircles of metal which are pasted upon their front surface. There is nothing between the revolving and the stationary plates except the charging rod leading from the Toepler machine to one field-plate of one of the stationary plates. This is not present exept in the first couple of the Holtz machine. The neutralizing combs project in front of the revolving plate at the places, top and bottom, where the revolving glass is just leaving the influence of the field-plates. The collecting combs from the prime conductors *P*

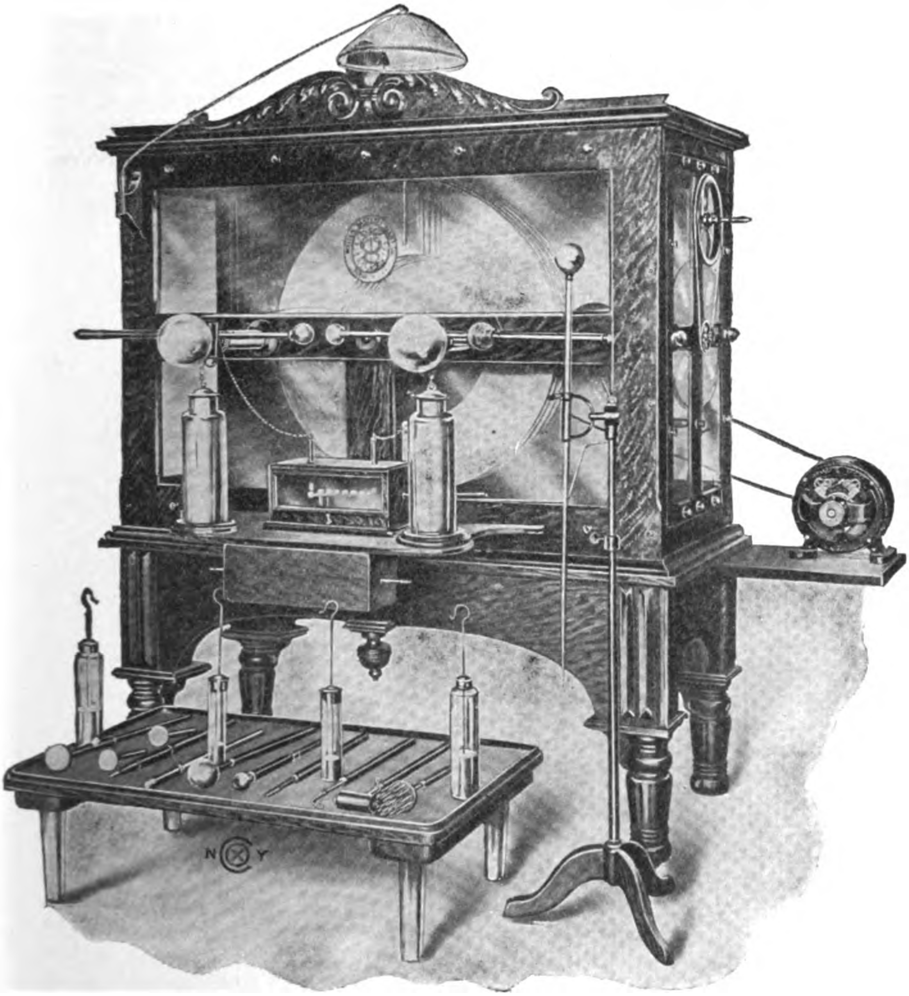

Fig. 28.—The Holtz machine.

and *N* project in front of the revolving plate at places, at either side, where the revolving glass has just entered the influence of the field-plates, near the edge of the metal semicircles. There is no connection between the revolving plate and the stationary plate with its field-plate. There are no collecting brushes to carry the free charge on the revolving plate to the field-plates, but this is accomplished by a convective discharge or effluve between the revolving glass plate and the metallic semicircle connected with each field-plate. The revolving plate being of glass, is itself a non-conductor, and is made still more so by a varnish of shellac; and nothing whatever touches or rubs over its front or back surface. At a certain stage any one portion of the revolving glass plate may have a positive charge, which it has received by a convective discharge from the combs of the prime conductor and a negative charge induced in it by the field-plate. This particular part of the revolving glass plate retains these two charges, bound upon its surfaces by mutual attraction, just as is the case in a dissected Leyden jar, where the positive and negative charges remain upon the glass after the outer and inner metal coats are removed. Each successive portion of the revolving glass undergoes various transformations by induction and by convective discharges, just as if it were revolving in space separated from every other part of the same plate. Electrically, each part is separated as long as the glass and its shellaced surface are free from dust and moisture. When these conditions are not fulfilled, the Holtz machine will produce only a feeble discharge, and perhaps none at all.

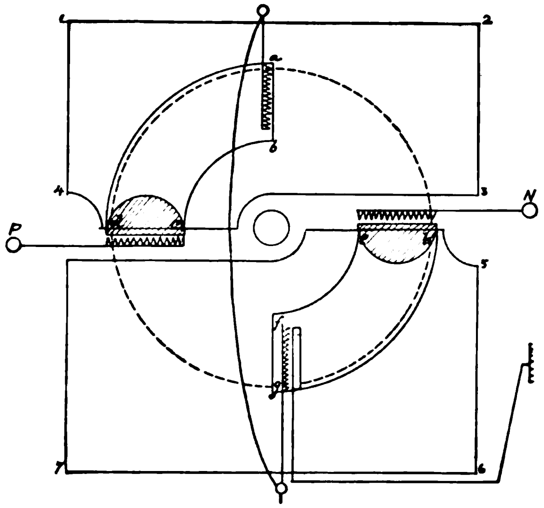

Fig. 29.—Principle of the Holtz machine.

When a multiple plate Holtz machine is charged, it will not reverse polarity so long as it is running and the sliding rods are separated several inches. When the atmosphere inside of a Holtz machine has considerable moisture in it, the polarity may reverse if the sliding rods are brought in contact. When a Holtz machine loses its charge, then upon recharging it, the polarity may be reversed, but this is due to the fact that the polarity of the charging machine has reversed. The Holtz machine itself will not reverse polarity as long as it retains the original charge.

It must be noted that while we speak quite definitely about the way in which an influence machine generates electric charges, the subject is a purely speculative one, and the facts, if they could be known, might vary considerably from our conception of them. That when an influence machine, even with the latest improvements, is started up, one pole will sometimes be the positive and sometimes the negative is very curious.

Any of the influence machines may be made with plates of other material than glass; hard rubber has many desirable features; it does not attract moisture, and is not so heavy or so apt to break under the strain of an excessive speed of rotation as glass. On the other hand, it undergoes a slow process of degeneration, and is also liable to warp and lose its perfectly flat shape. Mica plates are made of mica split in infinitesimally thin pieces, mixed with powdered shellac or a similar substance, and subjected to an enormous pressure while heated to the proper degree. Machines with mica plates work excellently, and while one would suppose that the plates would disintegrate in time, the manufacturers say that they have never had a plate returned to them in this condition.

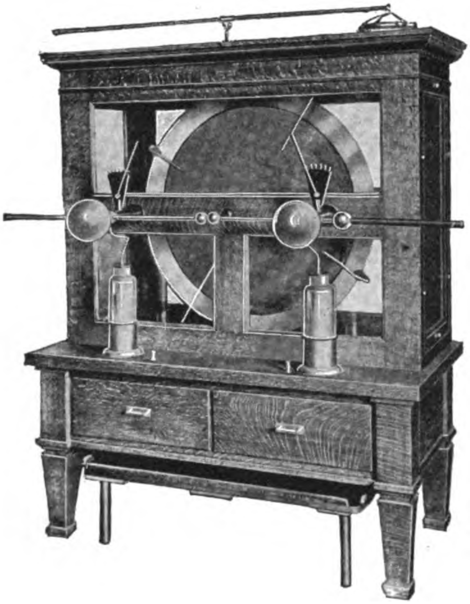

Fig. 30.—Baker paper disk static machine, type B.

The Paper Disk Static Machine (Fig. 30).—The static machine made by the Baker Electric Company is a Toepler machine, and is inclosed in a glass case, but usually does not require calcium chlorid inside the case to absorb moisture.

A suitable machine for x-ray work is known as an eight-plate machine, having four revolving paper disks and four stationary glass plates. The plates make 2000 revolutions a minute, a two-horse-power engine or motor being required to run the machine. Excellent radiographs of the foot can be made in six seconds, and of the chest in thirty seconds.

Each paper disk is made of about 24 full-sized sheets of bond paper, coated with shellac and other gums, to harden the shellac, for the latter does not harden unless exposed to the air. The whole mass is compressed between hot metal plates and then allowed to cool slowly while under pressure. The result is a disk about ¼ inch thick, which is practically unbreakable. It sounds like a piece of iron when struck by metal. Moisture has less tendency to condense upon it than upon glass, and the plate will stand the strain of 2000 revolutions a minute, while the normal rate with revolving glass plates is 350 revolutions a minute.

The revolutions being five or six times as rapid, the discharge is more nearly continuous than from a glass plate machine. It is twenty times as nearly continuous as the discharge from an induction coil. The discharge from a powerful paper disk static machine through an *x*-ray tube is, therefore, more nearly continuous, and the heating effect on the anticathode is very great. Some tubes will transmit 18 milliamperes of this current, but after about thirty seconds it is found that the vacuum has dropped to such a degree that the *x*-ray generated has no penetration. Generally speaking, the tubes which will stand the discharge for half an hour or so give excellent fluoroscopic images, but make poor pictures; while the best radiographs are sometimes made by tubes which will stand the current for hardly thirty seconds without breaking down.

The breaking down is attributed to the fact that the platinum is usually cemented or welded to the surface of the mass of copper provided for heat radiation. The cement in one case, or the flux used in the other case, gives out gas when heated and lowers the degree of vacuum.

Tubes have been made with an anticathode in which the copper backing is deposited on the platinum by electrolysis; the platinum is copper-plated. This does away with the evolution of gas from the cause just mentioned.

Another characteristic of the discharge is its comparative freedom from snapping. This is seen in the fine zigzag sparks which pass between the prime conductors of a static machine when they are separated beyond the range of actual white sparks. With most glass plate static machines there is considerable of this effect interfering with the effluve or simple violet luminosity. This snapping is a sort of condenser discharge, and depends upon the amount of metal surface in the construction of the machine. The paper disk static machine may be made to give no snapping at a distance of over three inches, while it gives an effluve or mass of violet luminosity twenty-two inches long. By suspending a number of separate sheets of tin-foil from the prime conductors, however, the snapping at once takes place.

Still, all composite plates are subject to some deterioration, owing to the action of the nitrous and nitric acid gases which are generated in a static machine. Another objection to a composite plate is that it is practically impossible to obtain a nearly uniform resistance, so that when static machines are made having more than two revolving plates, and having them made of a composite material, they may possibly prove unsatisfactory, owing to the fact that the revolving plates are liable to perforate.

The Size of Static Machines.—For ordinary therapeutic uses a machine with eight or ten revolving plates thirty or thirty-two inches in diameter, and making 300 revolutions a minute, is sufficient. Such a machine will also light up an *x*-ray tube so as to make possible a fluoroscopic examination of the extremities, or a radiograph of the same parts and the chest (either a much larger static machine or a transformer is required for practical *x*-ray work). Static machines have been made with revolving glass plates weighing a ton in the aggregate, and have given beautiful results with an *x*-ray tube. A static machine with sixteen revolving plates thirty inches in diameter is powerful enough for all practical purposes. This should be furnished with a half-horse-power motor.

Pole Changer.—The polarity of a static machine cannot be voluntarily changed, but, especially for *x*-ray work, it is often convenient to use a pole-changer—a jointed hard-rubber rod by means of which the connection of two wires with the two poles of the machine may be changed by simply reversing the position of the rod.

The Care of the Static Machine.—The modern influence machine gives a wonderfully steady output when in good order,—much more uniform than the current from the best induction coil,—but it is very sensitive to atmospheric and other conditions, affecting the insulation of the surfaces of the plates. The machine should be completely inclosed in glass and wood, and this case should be airtight. The room in which the machine is kept ought to be a dry one, and one on the second floor is sure to be better than one in the basement. If the case has to be opened for repairs, this had better be done on a clear dry day, and it should be left open as short a time as practicable.

The *moisture* in the air inside of the case has a tendency to collect upon the glass plates, and with it also the atmospheric dust and the metallic dust from the machinery itself. This deposit may cause such a lack of insulation that the machine will produce little or no discharge. Several different ways of preventing this have been suggested, the best being by the use of calcium chlorid, a powerful absorbent of moisture. A generous quantity of this should be used. In a case measuring 2 x 3 x 4 feet, and containing a six-plate static machine, two pounds of dry calcium chlorid should be placed in deep open vessels. As time passes this changes from a powdery white mass to a dirty slush or melting snow appearance. After it has become completely saturated with moisture, of course, its usefulness is at an end. It may be regenerated by drying in a hot oven, or it may be replaced by fresh material. Needless to add, if the calcium chlorid is bought in quantities, it must be kept in sealed tins or glass until used. A larger quantity will be needed for a larger machine. A handful of calcium chlorid in a shallow saucer is quite inadequate to the purpose. It is very important to reduce the amount of dust produced in a machine to a minimum. The use of aluminum instead of brass or iron for the parts of the machine inside the case is to be recommended wherever practicable. Aluminum does not oxidize or produce much metallic dust. With a properly constructed case and machine and with an occasional renewal of the proper amount of calcium chlorid a static machine should run for two or three years without any further attention. At the end of that time it may well require very complete overhauling. The inevitable deposit of metallic dust will have to be washed off of the plates and all the other interior parts of the machine, with a light additional coat of shellac applied to the glass surfaces.

Another method of dealing with the subject of moisture is to have a gas or other flame so arranged as to carry a current of hot air and products of combustion into the case. This is a step in the wrong direction. Hot air will carry more moisture than cold, and watery vapor is one of the products of combustion when gas or any of the ordinary illuminants are burned. The proof of this is readily seen on any very cold day, when the windows of a room in which a number of gas-jets are burning will be covered with moisture, while those in a room in which the gas has not been burning will be free from it. With a static machine benefit might be obtained from heat if the air were heated, but kept separate from the products of combustion.

This can be easily done by placing one or two 32 candle-power electric lamps inside of the glass case, with a switch on the outside, so that they can be turned on or off as required.

In a very damp, warm climate, a static machine may be thoroughly dried in fifteen minutes by means of compressed hot air. Inside the case of the machine at one end have an electric toaster supplied with the regular electric light current. At the other end pump in compressed air at a pressure of about 25 pounds to the square inch. This can be done every day if necessary.[1]

Another method is to keep from 20 to 100 pounds of unslaked lime inside the case of a static machine. This works excellently as an absorbent of atmospheric moisture. The lime must be wrapped up in two thicknesses of cloth, to prevent particles from flying all over the interior of the machine.

In an emergency, for a single session, a freezing mixture of ice and salt in deep glass or earthenware vessels, such as half a dozen preserve jars, placed inside the case, will cause the moisture to condense upon the glass vessels, and thus free the machine from moisture. If glass jars are used to put the ice and salt mixture in, it is always well to place them in saucers or plates, so that the first condensation will be taken care of without wetting the bottom of the case. This will often save the day, but not always.

From the fact that so many ways are recommended for dealing with the subject of moisture, it will be gathered that a static machine is an uncertain quantity. Under unfavorable conditions it will not run well more than half the time throughout the summer. This is one reason why the static machine has been to a great extent abandoned as a source of electricity for the *x*-ray. There is good reason to believe, however, that a properly constructed static machine, properly taken care of, will work regardless of environment. Such a machine at a hospital in Boston is in a basement only a few feet from the sea-water, and still works perfectly.

The condition of the atmosphere outside of the case of the static

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[1] C. A. Weiss, M. D., Jour. of Advanced Therapeutics, October, 1912, p. 417.

machine has, of course, much to do with the condition of the air inside, for no case can be hermetically sealed, but the condition of the air of the room has also an effect upon the efficiency of the application of the charge after it has been generated by the machine. If the air is very damp, it ceases to be a good insulator, and much of the charge leaks away from the prime conductors by a convective discharge. The ideal room would be one through which the refrigerating pipe ran in summer, reducing the temperature of the air to between 60° and 70° F., and causing much of its contained moisture to condense as a thick layer of white frost upon the cold pipes.

All exposed metallic parts should be round and polished and kept clean. Metallic points or particles of dust would dissipate the charge by convection. Wherever any metallic parts of the machine which conduct electricity pass through the case, they should not come in contact with wood, but should be insulated by hard rubber. While wood is a poor conductor of electricity, the extremely high voltage possessed by static electricity requires the most perfect possible insulation.

Starting an Influence Machine.—In starting a Holtz machine provided with an auxiliary Wimshurst or Toepler machine, the discharging rods should be an inch or two apart, and after the motor has been turned on and the glass plates have begun to revolve, the Toepler machine should be given a few turns by hand. Soon a series of sparks will begin to pass across between the discharging rods of the Holtz machine. After this the Holtz machine may be allowed to run alone. It may happen that the Holtz machine retains its charge from the last time it was used, and in that case it is not necessary to give the preliminary turns to the Wimshurst or Toepler machine. If the Holtz machine refuses to produce a discharge in hot or damp weather, the difficulty may often be overcome by disconnecting the machine from the ground or from the platform—in other words, removing any means of conducting away the discharge. The maximum efficiency of an influence machine can never be obtained without a certain external resistance, and this is most effectively provided by making it necessary for the discharge to take place across an air-gap. With the discharging rods together, of course, there is no external resistance at all, and with the patient directly or indirectly connected with the machine, the electricity finds so ready an escape by conduction and convection that the external resistance becomes very much less than it would be if a charge could escape only from the bare discharging rods separated by an air-gap. If, then, the connections are all made for the treatment of a patient and the apparatus refuses to develop a charge, the difficulty may often be overcome by disconnecting the conductors leading from the static machine, and separating the discharging rods about an inch. The necessity for a sufficient external resistance in order to obtain the maximum discharge is the reason that spark-gaps often have to be placed in the circuit with an x-ray tube excited by a static machine.

Accessory Apparatus for Treatment by Static Electricity.—The insulated platform should be of wood, measuring about two by three feet, and with glass legs about nine inches high, which should be kept free from dust and moisture, either of which would reduce their insulating qualities. The platform should not be in contact with any other object, and not near enough to anything else to lose part of the electric charge by convection or a brush discharge to neighboring objects. A connection is generally made from one pole of a static machine by means of a *shepherd's crook*, a brass rod five feet long, which hooks over a prime conductor and rests upon the platform. A square piece of sheet metal an eighth of an inch thick lies upon the platform, and the shepherd's crook may rest upon this or upon the wood, at a variable distance from the patient's chair (Fig. 31). One leg of the chair may rest upon the metal, or they may all be at a variable distance from the metal plate. Then, again, the patient's feet may rest upon the wooden platform at a variable distance from the metal plate, or they may rest upon the latter. These different combinations regulate the strength of a charge received by the patient seated upon the platform, by varying the resistance through which the charge must pass to reach him

The *crown* is a ring of brass about eleven inches in diameter, with a series of points projecting downward. It is extended above the patient's head by a brass rod attached to the woodwork of the top of the case of the machine, and its height is adjustable. It may be connected with the pole which is not connected with the insulated platform, or it may be grounded. Brass chains are used for making these and various other connections between the static machine and its accessory apparatus.

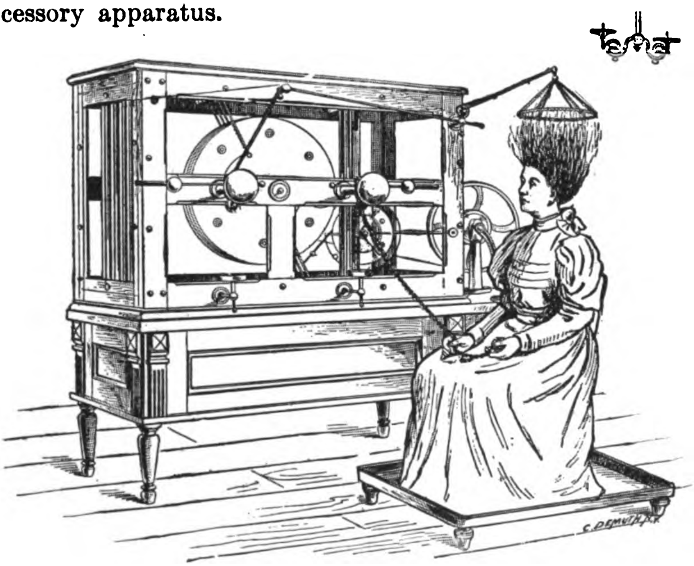

Fig. 31.—The static head breeze. Direct method.

Leyden jars of different sizes are arranged to be hung from the poles of the machine, or are placed upon a shelf at the front of the case, so arranged that two Leyden jars rest upon it. If the Leyden jar spark is desired, the outside coatings of the two jars, are connected by means of a separate rod; or some machines are so constructed that this rod is mounted under the shelf in the form of a lever. When this arrangement is used, there is a label marked "sparks" so placed that when the handle is in a line with it, the rod underneath connects the outside coatings of the two jars. If the Leyden jar spark is not desired, it is always best to remove the Leyden jars from connection with the pole pieces of the static. This is advisable for two reasons: first, that when they are connected, even though the outside coatings are not connected, still the Leyden jars impart a sharp quality to the current administered to the patient, which is usually very undesirable; second, when the jars are left in connection, it is possible that, inadvertently, they may become connected so that the patient would receive the discharge from the two jars, which would give a very violent shock. As this is absolutely avoided by having the jars removed, it is to be recommended.

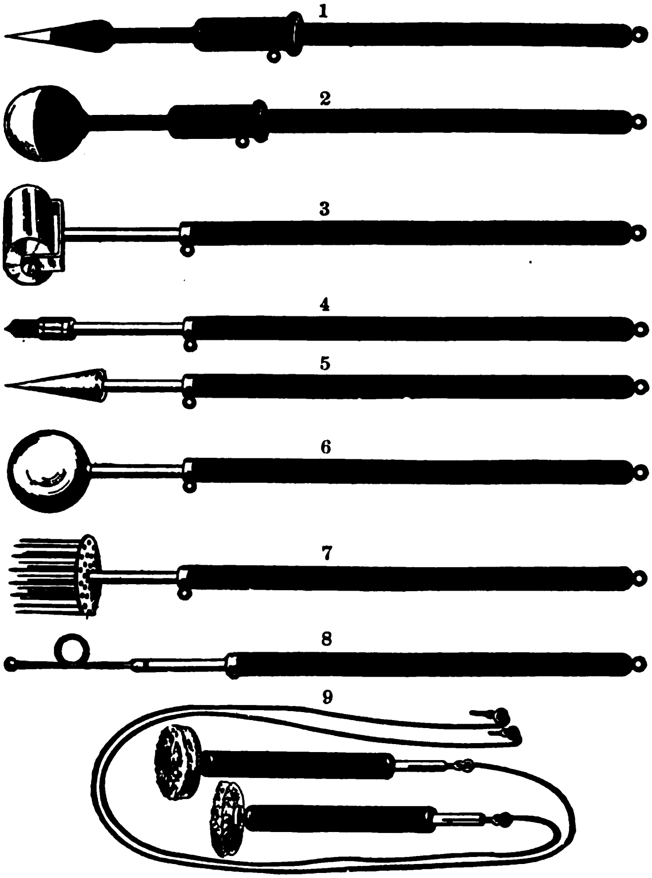

Fig. 32.—Static electrodes: 1, Wood point; 2, wood ball; 3, massage roller; 4, carbon point; 5, brass point; 6, brass ball; 7, brass brush; 8, chain-holder; 9, cords, handles, and sponges.

A *set of electrodes* (Fig. 32) have insulated wooden or hard-rubber handles, and a metal ring for the attachment of a chain conducting the charge to or from the electrode. These electrodes terminate in different ways—one has a metal point, another has about 20 parallel pointed brass rods; another has a gas-carbon extremity; another has a two-inch brass ball; another a two-inch wooden ball; another has a brass roller. There are two sponge electrodes with heavily insulated handles and a pointed wooden electrode.

A *chain holder* with an insulated handle is of brass, in which a single open turn has been made, so that it can easily be hooked around the chain leading to the electrode. It enables the operator to keep the chain from contact with the patient or any other object, and so prevents shock or loss of electricity.

A *concentrator* (Fig. 33) is a brass rod mounted on a metal tripod, and so arranged that its pointed extremity may be directed toward any part of the patient. A chain leads to it from one pole of the machine or from the ground.

One way of measuring the voltage of a static machine is by noting the length of a spark which will pass between the discharging rods while the machine is not connected with any other object. The distance across which a spark or disruptive discharge will take place through the air depends on the voltage or electric tension, and also upon the nature of the discharging surfaces. A spark 8 mm., or one-third of an inch, long between polished metal balls 3 cm., or one and one-quarter inches in diameter, represents a tension of about 20,000 volts. Other estimates covering a variety of conditions vary from 10,000 to 35,000 volts per inch of spark length. This has reference to the spark which passes completely across with a clear loud sound, and not to the brush discharge, which is seen when the poles are very far apart, and which is visible as a complete bridge over the gap only when the room is darkened. Without the Leyden jars there is perhaps not a very sharp line in the case of static electricity between the true disruptive discharge and the convective discharge, but with the Leyden jars and a rod connecting their outer coats, there is no mistaking the disruptive discharge or true sparks for anything else. However, it is the discharge from the bare poles which it is important to measure, and which indicates the voltage or the difference in potential between the poles. The voltage produced by a static machine can never greatly exceed that represented by a spark-gap of half the diameter of the revolving plates, or the distance between the nearest charged metallic parts—usually the discharging rods of the machine. This is especially true of small machines having two revolving plates. A machine was exhibited in Washington which had sixteen revolving glass plates, thirty-two inches in diameter, and a speed of five hundred and fifty revolutions a minute, developing a spark over nineteen inches long. In the winter time we frequently

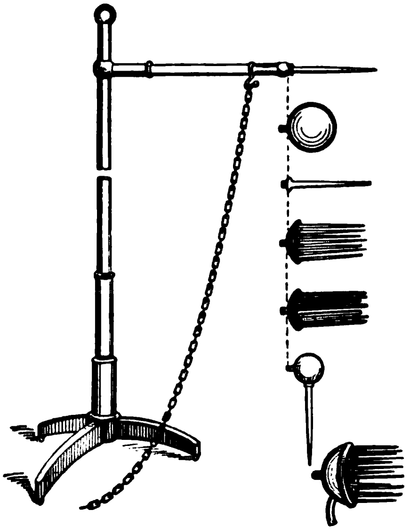

Fig. 33.—A concentrator.

have machines having ten or twelve revolving glass plates thirty-two inches in diameter, that will give a spark seventeen to seventeen and one-half inches long. More than that, the statement refers only to the Holtz type of machine. The Toepler-Holtz type, which is the type used by the mica plate, Betz, and other Chicago manufacturers, will, as a rule, develop a spark one-third the diameter of the revolving plate. No matter how efficient a static machine may be, the voltage is limited as above, just as the pressure in a steam-boiler is limited by the safety-valve. The hottest fire cannot produce a greater pressure than is required to raise the safety-valve. With the static machine, if there is a tendency to produce a higher voltage or pressure, the resistance of the intervening air-gap is overcome, and a discharge takes place, limiting the voltage to the specified amount. In applying electricity produced by a static machine the voltage can be regulated by the speed at which the revolving plates are rotated.

The Tension of Static Machines.—The discharging distance between two metallic spheres 1 cm. in diameter is different for varying tensions.

Distance of the Two Spheres.		Difference of Potential.
Centimeters.	Inches.	Volts.
0.1	0.04	4,830
0.5	0.20	16,890
1.0	0.40	25,440
1.5	0.60	29,540
2.0	0.80	31,350
3.0	1.20	37,200
5.0	2.00	45,900
10.0	4.00	56,100
15.0	6.00	61,800

The above table is compiled from Joubert's "Traité d'Electricité."

When one pole of a static machine is grounded and the other insulated, the potential of the latter rises to twice the figure it had when both poles were insulated. The pole that is grounded has a potential of zero, and the other has its potential doubled, so that the original difference in potential is maintained.

The Efficiency of Static Machines.—A test of a Holtz machine has been made by Professor Samuel Sheldon, of Brooklyn, New York, in which the efficiency was shown to be more than 30 per cent. The static machine was run by a one-quarter horse-power electric motor, so that the power applied was accurately known. The poles of this static machine were connected with the poles of another static machine which was not provided with a motor. The discharge of static electricity through the second static machine caused its glass plates to revolve rapidly in a contrary direction, and the power thus generated was measured by means of the brake resistance which it would overcome.

The Output of Static Machines.—The output of a static machine is the quantity of electricity which the sparks carry across between the two balls in a second. It varies according to the efficiency of the machine, between $\frac{1}{10,000}$ and $\frac{1}{1000}$ or more of a coulomb. This is equivalent to a current of from $\frac{1}{10}$ to 1 or more milliamperes.

Lane's bottle for measuring the output of a static machine gives the output in microcoulombs per second, which is equal to milliamperes. The calculation is based upon the capacity C (in microfarads) of the Leyden jar (Lane's bottle), the potential V in volts required to spark across the air-gap of the Lane's bottle, and N, the number of sparks per second. The output D in microcoulombs per second is given by the formula—

$$D = \mathrm{NVC}.$$

The distinction between quantity and potential or voltage is illustrated by the steam engine. In the boiler the pressure is so many pounds to the square inch, without reference to the size of the boiler or the amount of water converted into steam in a certain time; the last two elements, without regard to pressure, convey the idea of quantity. A static machine with sixteen revolving plates will generate a much greater quantity of electricity than one with only four revolving plates, and so will a machine revolving at a higher rate of speed than another, but if the plates are of the same diameter and the construction and insulation are equally perfect, the voltage produced will be the same. A machine with a greater number of plates and a more rapid rate of revolution will produce a better effect by maintaining a more constant supply of electricity at a certain potential, making up in this way for the constant losses by convection and conduction. The quantity of static electricity in a charged body may be measured by the repulsion it produces upon a similarly charged body, or its attraction for one oppositely charged. The force exerted varies directly as the charge and inversely as the square of the distance, but the latter fact is only exactly true between points and not between extensive surfaces.

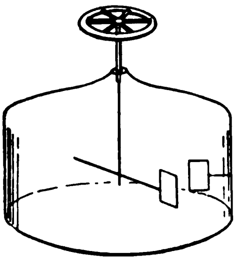

Fig. 34.—Coulomb's torsion balance.

Coulomb's torsion balance (Fig. 34) consists of a glass case containing two metallic squares, one fixed and one fastened to a rod suspended horizontally by a wire; both metal squares are similarly and equally charged, and the insulated handle at the top of the suspension wire must be turned a certain distance in a direction opposed to the force of repulsion in order to bring the horizontal rod into the standard position. From the amount of torsion or twisting of the wire can be calculated the amount of electricity.

The *quadrant electrometer* is so called because the repelling surfaces are quadrants or quarters of a circle. These deflect an aluminum needle suspended by a fine wire, and the degree of deflection is seen by the motion of a mirror observed through a telescope.

For use in measuring the dosage of static electricity a piece of sheet metal about an inch square is applied to a given part of the patient by means of an insulated handle. It receives a charge proportional to the density of the charge at that part of the patient, and this is carried with as little loss as possible to the electrometer. The carrier is placed on a metal platform projecting from the top of a glass case, and communicating by means of a metal rod with the electrometer vanes inside the apparatus.

Arrangement of Static Machines.—Fig. 35 shows the general arrangement of a static machine with a Leyden jar hanging from each pole, and a brass rod connecting the outer coats of the Leyden jars. This arrangement gives the most powerful sparks, and in the experiment

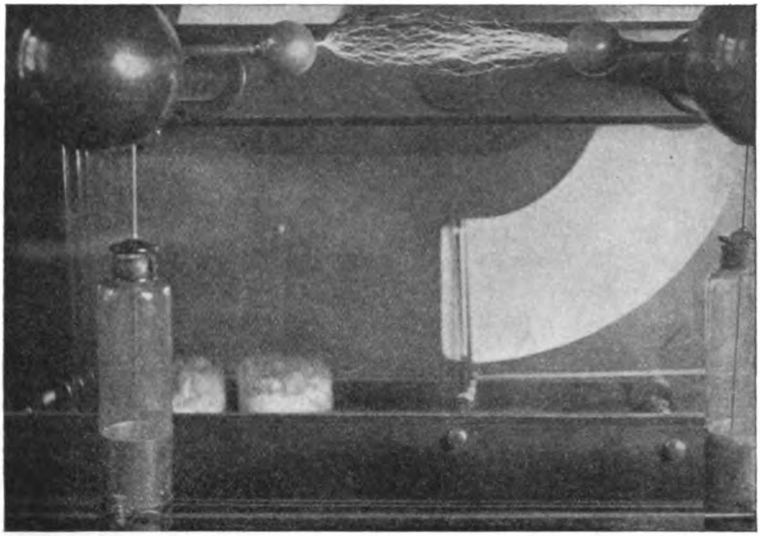

Fig. 35.—Static machine and Leyden jars arranged for sparks.

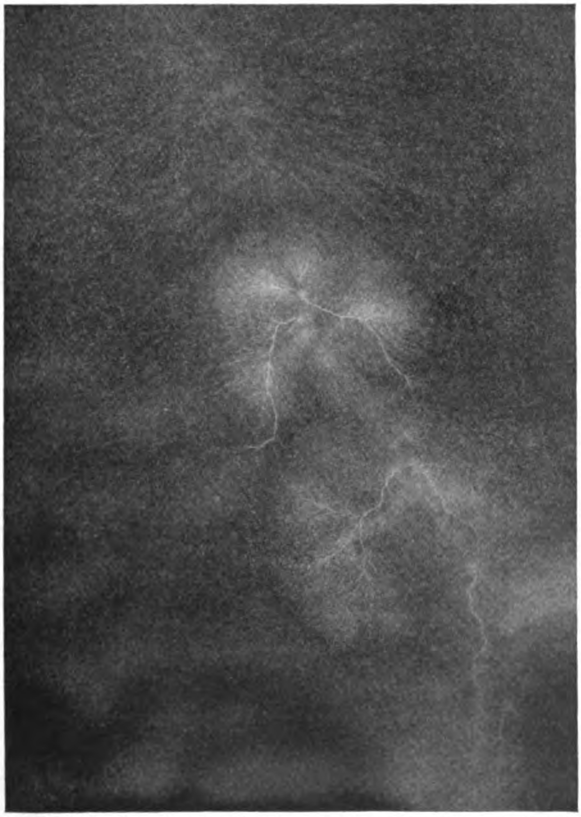

Fig. 36.—Effect of a Leyden jar spark upon a photographic plate in black and orange envelopes.

illustrated a brass chain is seen hanging from the connecting rod and extends to earth connection. The two discharging rods of the static machine are separated by about nine inches, and the sparks (Fig. 36) were passing across at the rate of about two a second. The picture was taken with an exposure of fifteen seconds, and shows the path of all these different sparks. It will be noted that the sparks from the positive pole start off practically in a single straight line, and become divergent at a distance of about an inch from the terminal, so that this picture of a number of successive sparks reproduces the familiar fox-tail appearance of the brush discharge, which takes place from the positive terminal when the Leyden jars are not used. Even then, perhaps, the fox-tail appearance is due to a very rapid succession of single sparks following the paths indicated in the present picture. It looks, however, like a simultaneous group of sparks. The positive terminal shows a number of little green stars on the surface of the metal, and the discharging spot may be displaced by a bit of wood like a match. The negative end of the succession of sparks shown in the picture leaves the terminal from quite a wide distribution, just as was the case in the negative breeze about the Leyden jars. The negative terminal shows a pure violet, with only once in a while a white spark right on the surface of the metal. At the lower left-hand corner of the picture are seen the two open dishes of pure calcium chlorid. Each of these contains a pound, and the machine has never failed to work, winter or summer. The broad white sector is one of the field-plates on the foremost of the stationary plates.

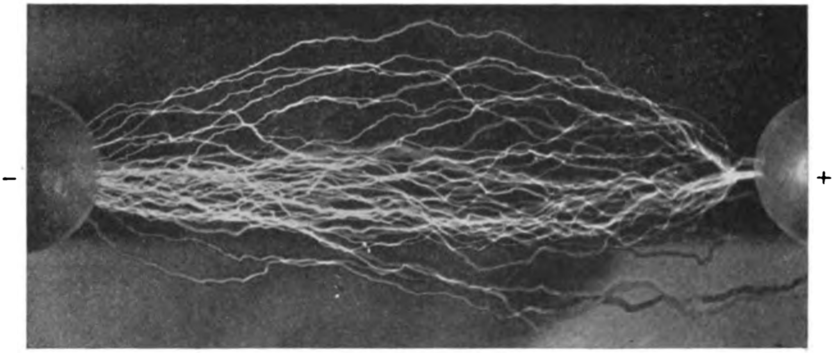

Fig. 37.—Sparks from static machine with suspended Leyden jars.

Fig. 37 again shows the distribution of a succession of sparks, the left-hand end being the negative and the right the positive terminal of a static machine. The distance was six inches, and connected Leyden jars were used. All the sparks are united in a single trunk at the (+) positive pole.

SOME PRACTICAL ELECTRIC UNITS

For electric measurements the fundamental units are the *centimeter*, for length, the *gram*, for mass, and the *second*, for time; these forming the C. G. S. (centimeter, gram, second) system.

An **ohm** is the resistance to the passage of electricity offered by a column of mercury $106\frac{3}{10}$ centimeters high and 1 square millimeter in cross-section, at a temperature of 0° C. It is about the resistance of a mile of copper trolley wire or of a single foot of No. 40 (American gauge) copper wire. Iron has about six and one-half times the resistance of copper.

An **ampere** is the unit of electric current. It decomposes 0.000945 gram of water per second. It will deposit 0.001118 gram of silver per second in an electroplating cell. A milliampere is a thousandth of an ampere.

A **coulomb** is the unit of electric quantity; it is the amount of electricity carried by a current of 1 ampere in a second.

A **volt** is the unit of potential; it is the electromotive force which will maintain a current of 1 ampere in a conductor whose resistance is 1 ohm. A standard Daniell cell produces about 6 per cent. more than one volt.

A **farad** is the unit of electric capacity. It is the capacity defined by the condition that 1 coulomb charges it to the potential of a volt; a microfarad is a millionth of a farad. These latter measurements are somewhat analogous to the bushel and quart and cubic foot of ordinary measurements. A condenser which is of a capacity of one-third of a microfarad must contain 1200 square inches of tin-foil, and will require one-third of a millionth part of a coulomb to charge it to a potential of one volt.

A condenser of one-half microfarad capacity, as required for a half-inch induction coil, forms a block of tin-foil and paraffined paper about one-half inch thick, and four and one-half inches wide, by six inches long.

Other Measurements of Static Electricity.—A measurement of static electricity by the electrometer indicating attraction or repulsion is really a test of its tension or voltage, rather than of its quantity or *amperage.* The latter is exceedingly small, but it is perfectly possible to measure it. For example, a number of discharges from a Leyden jar of a certain size will decompose a very small amount of water, and the result in hydrogen and oxygen gases can be measured. Another example is seen in the test which the author applies for determining which is the positive and which is the negative pole of a static machine in operation.

The *pole detector* is a sealed glass tube with leading-in wires of platinum, and nearly full of some liquid, such as a solution of iodin in water and iodid of potassium, which becomes colored at the negative pole when the liquid is decomposed by the passage of an electric current. Even with a static machine the discoloration is distinctly visible, and serves as a reliable test of polarity, but both of these tests for quantity indicate such an exceedingly minute amount of chemic change that the therapeutic effect of static electricity is evidently not dependent upon an electrolytic action upon the tissues or fluids of the body, that is, except as will be subsequently seen in a subatomic relation. This would not be discoverable by the ordinary means of chemic analysis.

Nevertheless, as applied to machines having eight or more revolving plates, the polarity of the static current has a most decided effect in the treatment of certain forms of headache. One pole over the head will increase the headache, while reversing and putting the other pole over the head will relieve the headache. In using static electricity for its counterirritant effect we always make the electrode negative, and the difference in the effect is easily noticed by the patient. When the electrode is negative, it feels like a stream of fine sand striking against the skin, whereas when the electrode is positive, it feels like a cool breeze blowing.

Another form of treatment in which the polar effect is most marked is what is known as the *wave current.* You will find that most authors speak most favorably about connecting the positive pole with the patient. A still further indication of the polar action is in the operation of an *x*-ray tube.

A d'Arsonval milliamperemeter, dependent upon the deflection of a suspended electromagnetic coil, may be used to measure the amperage of a static discharge as applied to excite an *x*-ray tube, and will perhaps indicate the *presence* of from the fraction of a milliampere to two or three or more milliamperes. A hot wire milliamperemeter can also be made satisfactorily to record these very small currents. In the case of a discontinuous discharge like that from a static machine, it is very doubtful, however, whether the milliamperemeter indicates the true amount of electricity which is being transferred, although it does so when it is used to measure a continuous current, like that from a voltaic battery.

The amount of force required to rotate the glass plates in a static machine has to overcome two factors—the ordinary frictional resistance to the motion of that amount of glass, and, second, the resistance due to the attraction of the two forms of electricity for each other and the power required to separate them. In a crude experiment by the author-a six-plate Holtz machine run by a one-twelfth horse-power electric motor showed a speed of rotation 2 per cent. greater before the machine had been charged than afterward. In other words, about one-fiftieth of the power was apparently consumed in the actual separation of the electricity into positive and negative charges. It is an established fact that the amount of power is the same whether in the form of mechanic motion or of electricity, so that in the case of the static machine all but about 30 per cent. of the power put into it is wasted. This makes the static machine the least economic of all sources of electricity, and it has no industrial application at all. The other two great sources of electricity—chemic action and electromagnetic induction—convert a greatly vaster percentage of the power consumed into electricity, and where high voltages are necessary, these may be obtained with practically no loss by means of coils and other converters which modify the electricity from these sources.

Voltage or potential or electromotive force is the force which tends to cause electricity to pass between two points so as to cause a union of their charges, positive and negative, producing a complete or partial neutralization. In the case of static electricity, voltage is chiefly of importance in determining the distance across which a charge will flash in the open air, or the way in which it will pass through the partial vacuum of an *x*-ray tube. In the case of the lesser voltage and vastly greater amperage of dynamic electricity, voltage is chiefly of importance in determining the quantity of electricity which will pass through a conductor having a certain resistance.

Some of the facts regarding voltage and amperage may be typified by a large bag of water with a long pipe leading from it. When the open end of the pipe is at the same level as that of the water in the reservoir, there will be no flow in either direction, and the condition is analogous with that of an uncharged conductor. When the bag is raised from the ground, the water will begin to flow through the tube if the other end is open, or, if that is closed, the water will be under a certain pressure, producing a tendency to motion if an opening were made. This condition represents the case of dynamic electricity produced by a battery or dynamo, and causing a current of electricity if a connection through a conductor is made between two points which are of different potential. Or a pressure is produced tending to cause a current if a connection were made. As in the case of the water, the amount of electricity which will flow through the conductor in a certain space of time depends upon the pressure and upon the resistance. In the case of the water, the resistance is dependent upon the size, length, and shape of the pipe through which it must pass, while with electricity it depends upon the size, length, and material of the conductor, and also upon an inductance which, if present, may impede or augment the current. This matter of inductive resistance is of the very greatest importance in the construction of coils and similar apparatus, and will be more fully discussed in another part of the book.

To typify the usual conditions of static electricity, the bag of water would have to be raised to an enormous height, and the column of water would have to be very small in cross-section, and the tube would have to be closed at the bottom. The water pressure under these conditions becomes perfectly overwhelming, and a powerful jet of water would be thrown through even a small opening. If there is no opening at all, the water in the pipe will be under great pressure, and will have a tendency to escape through the smallest kind of an opening, or even to burst the pipe. A body charged with static electricity and completely insulated is in the condition of the water when there is no opening. If the voltage becomes too great, the electricity breaks through the resistance of the air and a discharge takes place. This is somewhat as if the water-pipe had burst under the strain. In the case of water the pressure is due to the height, independent of the quantity of water, the pressure at the bottom being fifteen pounds on every square inch of surface for thirty-four feet of height, whether the amount of water at that height be one gallon or a million gallons. And if a single gallon of water is at a height of 340 feet, the bursting pressure at the bottom will be 150 pounds to the square inch, exactly as would be the case if a million gallons were raised to the same height. The amount of work required to raise the larger amount to that height would, of course, be proportionately greater, and so would the amount of work performed by the greater quantity in returning to the original level, but the pressure would be the same. A body charged with static electricity is comparable to a very small quantity of water raised to a great height. The effect of its discharge is due almost entirely to its pressure, and hardly at all to the quantity. The effect of a discharge of electricity of extremely high voltage and infinitesimal quantity is somewhat the same as the effect of a high-pressure stream of water from a force-pump washing out sand and gravel from a hillside by its mechanic force, but producing no appreciable action in dissolving the ingredients of the sand and gravel. The effect of great quantity, even if under small pressure, is exemplified by the caverns and passages with which the solid rock in the Mammoth Cave of Kentucky has been honeycombed by the solvent action of water percolating through the ground.

The condition of the opposite charges in a Leyden jar or other condenser is illustrated by that of water in a U-shaped tube. The water on either side is maintained at a high level by the pressure of the other column of water, and both columns will remain quiescent and at an equal level until either a large or a small opening is made at the bottom, allowing both to escape from the tube and mingle in a single mass at the natural or neutral level. A Leyden jar so overcharged as spontaneously to discharge is like such a U-shaped tube, in which water has been added to such a height that the walls of the tube have given away and the water has escaped, or a still better comparison is with two equal weights hung at a great height by a cord fastened over a pulley; either one can be moved up or down as if not possessing any weight at all as long as it is balanced by the other weight. They remain quiescent until the cord breaks, and then both fall to the ground with a crash.

SOURCES OF HIGH ELECTROMOTIVE FORCE OR STATIC ELECTRICITY

Natural Sources.—*Lightning* is due to a very powerful discharge of static electricity. The charge is originally produced by the evaporation of sea-water. In a thunder-cloud thousands of droplets coalesce into one, and this, with a smaller surface, has a higher potential or a more concentrated electric charge. This taking place all through the thunder-cloud results in such an increase in potential that a discharge to the earth takes place. A lightning flash is quite analogous to the discharge of a Leyden jar. The charged thunder-cloud induces an opposite charge in the nearest objects on the earth; the atmosphere forms the dielectric, and corresponds to the glass of the Leyden jar, while the thunder-cloud and the oppositely charged bodies on the surface of the earth correspond to the two metal coatings of a Leyden jar. The discharge is like a spark, sometimes as much as three miles long, and presents 300,000 oscillations a second. Its rending and heating effects are well known. Its effect upon human beings is described in another section of the book.

Animal vital processes all produce electric charges and currents, and in the case of the torpedo (*Raia torpedo*), electric ell (*gymnotus*), and the electric fish (*Silurus electricus*), well-marked shocks can be given at will.

Plant life is accompanied by electric charges and currents.

Mechanic forces in nature, such as rain, wind, the splitting of rocks or wood, produce electric charges.

The surface of the earth normally is negatively charged as compared with the air. The charge, however, is very small, being for the whole surface of the earth only five times the amount of electricity carried by 1 gram of hydrogen in electrolysis. There is normally a constant discharge from the surface of the earth to the air.

Normal Ionization of the Air Over the Earth.—This amounts to the production of about 2½ ions per cubic centimeter of air per second. The presence of radium in the crust of the earth has much to do with the phenomenon.

Rain carries with it to the earth an electric charge of greater or less magnitude which is more frequently positive than negative.

Light falling upon an insulated metallic body instantly gives it an electric charge.

Chemic processes and osmosis in nature produce electric charges and currents.

Sound will produce electric charges both directly and indirectly. An example of the latter is seen in the ordinary telephone.

Artificial Sources.—*Friction:* Accidental: Walking along the floor; combing one's hair. Purposeful: Rubbing amber, glass, hard rubber, sealing-wax, fur, wool or silk. Frictional electric machines.

Electrostatic induction: Holtz, Toepler, Wimshurst machines.

Contact of dissimilar metals (migration of ions).

Heat at junction of dissimilar metals and different points around the circumference of a ring. Heating tourmalin.

Electromagnetic induction.

Chemic action in the voltaic cell.

Other Mechanic Methods.—Splitting a piece of mica. Pressure upon a crystal of tourmalin. Percussion. Shaking mercury in a vacuum tube.

Crystallization of substances from their solutions.

Solidifications of molten substances.

Electricity a Universal Attribute of Matter.—All animate or inanimate matter is endowed with electricity, which requires only some exciting cause to make it manifest.

THE PHYSICAL EFFECTS OF STATIC ELECTRICITY

1. A thoroughly insulated body charged with either positive or negative free electricity—*i. e.*, unbound by any inductive influence—shows a repulsion of its component particles, which is most perceptible at its surface. In electrotherapeutics, for instance, the patient's hair may stand out in every direction from the head. It has an attraction for bodies oppositely charged or neutral. It produces or modifies static charges in neighboring bodies by induction. It does not undergo any perceptible change in weight or physical or chemic properties.

2. A body which, like one coat of a Leyden jar, possesses a bound charge of electricity, exhibits none of the properties of a charged body except an attraction for the oppositely charged coat.

3. A body from which free electricity is discharging undergoes extremely rapid and complex molecular, atomic, or subatomic changes. The discharge escapes either by convection, conduction, or as a spark or disruptive discharge. Particles of the body itself, even of solid metal, are torn away, and assist in carrying the electricity along the path of a disruptive discharge, and sometimes may be distinguished by the characteristic color which different metals give to the spark passing between them. The particles of metal are vaporized and rendered incandescent, and may be recognized by the spectroscope. The different appearances of the discharges from a positively and a negatively charged body have already been described (p. 26). When a body is discharged, the repulsion of its particles suddenly ceases, and loose but still attached parts of the body which have been spread wide apart by mutual repulsion will fall together. Among inanimate objects the best example of this is seen in the gold-leaf electroscope,

and in therapeutics the patient's hair is suddenly plastered down upon the head.

The magnetic effect of discharges of static electricity is seen in the magnetization of steel needles, and again the polarity of a ship's compass is sometimes changed in consequence of a lightning flash. No practical use is made of this effect of static electricity.

A chemic change takes place in the charged body during a static discharge. This is sometimes more readily perceptible in the air or other medium through which a discharge takes place. Delicate tests for chemic change, however, show that changes occur even in a solid body when a discharge of electricity takes place from it. In Fig. 38 a celluloid photographic film wrapped in two thicknesses of light-proof paper was charged by attaching it to the negative pole of a static machine. The numerous small white spots show the effect of the convective discharge upon the sensitized surface, and the large white spot, the effect of the disruptive discharge which occurred when the other pole was brought near to it. As the film was wrapped in closely fitting light-proof envelopes, it is probable that the effect was produced by a direct chemic action, and not indirectly by the light of the sparks. The chemic effects upon the human tissues will be considered under the head of Physiologic Effects.

Fig. 38.—Effects of disruptive and convective discharge upon a photographic film in light-proof envelopes.

The heating effect of the static discharge upon the charged body may be shown by the fusion of a fine wire forming the discharging point of a powerful battery of Leyden jars, or in treating a patient the author has sometimes had the point of one of his finger-nails scorched by the convective discharge. The finger in this case had been pointed at the patient, and acted as a concentrator, causing the discharge to take place from that particular part of the patient. Generally speaking, however, the heating effect upon the discharging body itself is very slight, and sparks may be applied through the clothes without danger of injuring the fabrics. A succession of short, powerful sparks applied at one spot, of course, will set fire to anything. The heating effects of powerful discharges of static electricity are shown when a tiny black hole is burned in a sheet of paper held between the two discharging rods of a static machine, with Leyden jars connected for spark effect. It is also shown when a building is set on fire by lightning.

Then, again, when a wooden clamp with some metallic parts is used for an *x*-ray tube, a spark from one of the wires may set fire to the wood.

Light is produced by static discharges, and is sometimes seen upon the charged bodies as a glow discharge or a silent or convective discharge of a violet color, and when this occurs from a single point, its shape is seen to vary with the polarity of the charged body. If this is negative, the glow has a globular appearance, as if the negative electricity were escaping into the air in all directions; and the glow discharge at a positively charged point has a branching or brush appearance, not deviating much more than 45 degrees from the direction in which the point projects. The glow discharge is not strictly an effect upon the discharging body, but upon the surrounding air. Solid particles in the air become charged by contact with the charged body and are then repelled. This discharge is seen as a violet light playing over the surface of the charged body when a concentrator of any kind is held in its neighborhood, but still not near enough to allow of a brush discharge or effluve. The difference between the two varieties is that the glow discharge is silent, continuous, and uniform, and is visible only close to the surface of a discharging body, while a brush discharge or effluve can be seen in the dark to fill up the space between the discharging bodies with a violet light, and is accompanied by intermittent sparks or flashes or by sound. Both produce a breeze sensation upon the human body, and both will take place through the ordinary clothing.

A static discharge produces magnetic and electromagnetic effects upon the discharging body, similar to those of dynamic electricity, but in such small amounts as not to be of any importance in therapeutics.

4. The effect upon the air from a discharge of static electricity through it has been partly indicated in the previous pages. The chemic effect is of importance. A portion of the oxygen is changed into ozone, and another small part of the oxygen is made to combine with some of the nitrogen of the air. The odor that accompanies the discharge of static electricity is produced by a combination of these two newly formed compounds. On the assumption that the ozone is of the principal importance, inhalers have been made (Fig. 39) in which a glass globe surrounds the spark gap and has two openings—one for the admission of air and the other leading to the patient's mouth and nostrils. Two glass vacuum electrodes form a spark-gap free from injurious metallic fumes. The nitric acid which results from a spark discharge through the air is not of much apparent value in therapeutics, but it is of tremendous practical importance in another way. All animal and

most plant life requires nitrogen in an assimilable form, but neither of them can utilize the nitrogen so abundantly present in the atmosphere. For all practical purposes the nitrogen is inert, and simply dilutes the oxygen which forms the most important part of the air as far as the daily life of plants and animals is concerned. Even the nitrogen which is absorbed and held in solution by rain-water and carried into the earth is not available for the nourishment of plants or animals. Where water power is abundant and cheap for the operation of dynamos, the high-tension currents produced by transformers may be passed through an air-chamber. A multitude of points produce a great many separate spark paths, and a spray of water or of an alkaline solution absorbs the nitric acid. By this process ammonia or nitrates can be synthetically manufactured for fertilizers more cheaply than they can be obtained from natural sources. The static machine could be used in the same way, but its output is much smaller compared with the amount of work required to operate it.

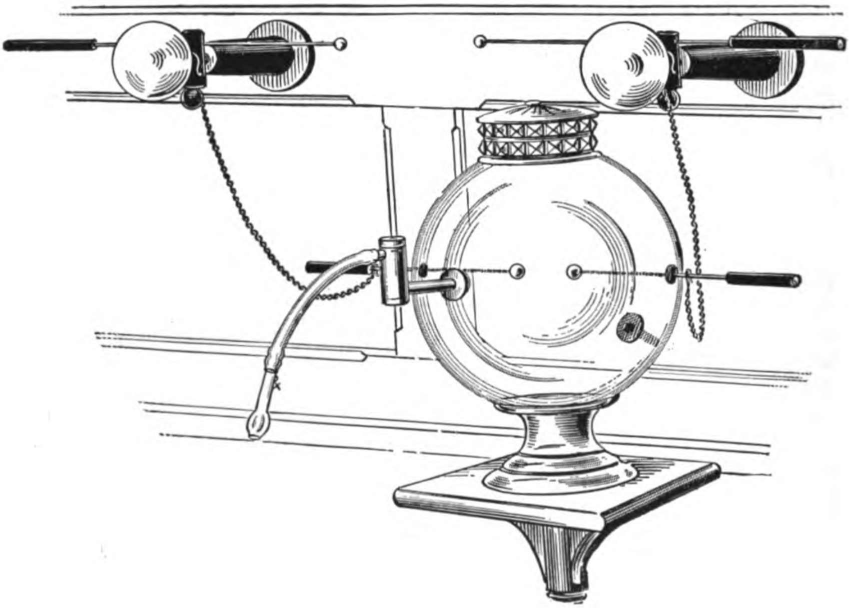

Fig. 39.—Ozone generator for use with static machine.

The air becomes condensed in front of the static discharge, and this produces heat with incandescence, and a sudden very great expansion of the air, followed by an equally sudden collapse on cooling. The sound of the spark is due to this cause. Heat, light, and sound are thus concomitant products of the passage of static electricity through the air in a disruptive discharge. The familiar experiment of lighting the gas by a spark from the finger-tip is an example of the heating effect of the static spark upon the air through which it passes. But the amount of heating of the air by a static discharge is so small that it has no practical importance; neither is the static discharge through the air employed for illumination, but both the light and sound of static discharges have important therapeutic effects of a mental character. Static discharges cause a clearing of the atmosphere by an effect upon the solid or liquid particles floating in it. These particles become charged with electricity, and are then repelled from the source of electricity, and tend to collect upon any non-conducting or poorly conducting surface in the neighborhood. This is a property of great practical importance in *x*-ray therapy. The *x*-ray tube, whether excited by a static machine or in any other way, is a source of static electricity, and causes a deposit of particles of dust, and, of course, of germs, if they are present, upon any surface near enough to be affected by its static induction. In exposing any ulcerated surface the possibility of infection from this source must be considered. If necessary, it may be guarded against by the interposition of a thin sheet of aluminum or other substance transparent to the *x*-ray.

The condensation of steam into drops of water, or the "pulverization" of steam, is a property especially of static electricity, and is not so apt to occur under the influence of high-frequency discharges. This is one of the features distinguishing the effluve or breeze from these two sources.

A **dielectric** is an insulating medium which, when it separates two opposite charges of electricity, permits them to exert through it upon each other the attraction which is characteristic of condensers like the Leyden jar. Not all non-conductors are equally good dielectrics, but among the best are air, glass, shellac, sulphur, gutta-percha, insulating oils, and a vacuum. Aside from the construction of condensers, the subject of dielectrics is of importance in determining the material to be used for insulating wires which are to carry different forms of electricity for various purposes. For all cases where ohmic resistance to the escape of the electricity through the covering of the wire is alone to be considered, gutta-percha forms an excellent insulating covering. This ohmic resistance is a name given to the resistance to the passage of electricity which corresponds to ordinary friction in the case of mechanic motion, and by which the electricity is partly converted into heat. It is a different matter from the resistance due to an inductive action in the circuit itself, which tends not to cause electricity to be converted into heat, but to cause it to escape like something of a disruptive discharge from the lateral walls of the conducting path. Where it comes to be a matter of a condenser action or of inductive resistance, as in the case of high-frequency currents, and the currents either from a coil or a static machine exciting an *x*-ray tube, other insulators not in the category of dielectrics are better. A thick layer of gutta-percha will not prevent the conducting wire from giving a shower of sparks if it is touched, or even if the hand is brought near to it, but a coating of paper or plaster-of-Paris of moderate thickness may be applied, and will permit the wires leading from an *x*-ray tube to be handled, or even to be touched together crossed, without any disagreeable spark. In this case there is a slight brush discharge which does not break down the insulation of the wires.

METHODS OF THERAPEUTIC APPLICATION OF STATIC ELECTRICITY

Some static machines are provided with two little shelves, upon which the Leyden jars may rest upon plates, which form a metallic connection with the external coats of the jars. When the jars are to be used, a brass rod is adjusted from the knob connected with the inner coat of the jars to the corresponding prime conductor of the static machine. There is an insulated handle which can be moved to various positions, marked "spark," "breeze," or "induced."

When this handle is turned to "spark," it moves a brass rod concealed beneath the case of the machine to a position in which it touches both the metal plates upon which the Leyden jars rest. A metallic connection is thus made between their external coats, just as is the case when a separate brass rod is laid across them in other makes of static machines. The tremendous detonating sparks obtained in this way are curiosities and might produce a psychic effect, but are rarely actually applied to a patient.

The other positions of the handle—"breeze" and "induced"—show that the outer brass rod does not form a connection with the Leyden jars. Connected with each brass plate is a binding screw, by which conducting wires may be placed in connection with the outer coat of the Leyden jar. These conducting cords may lead to sponge or other electrodes for application to the patient or may be grounded.

When the handle is in the position marked "breeze," there is also no connection made between the external coats of the two Leyden jars. But in this case the Leyden jars may be dispensed with entirely, for if they are left in position they are not connected with the patient. A shepherd's crook conducts the electric charge from one prime conductor to the insulated platform on which the patient sits, while a chain conducts the charge from the other prime conductor to the crown, or to some other effluver by which a breeze is applied to some portion of the patient.

In other static machines the Leyden jars are simply suspended from the poles of the machine when required.

Static Insulation or Static Bath or Franklinic Bath.—Fig. 40 illustrates the mildest way. This is known as *static insulation* or *static bath.*

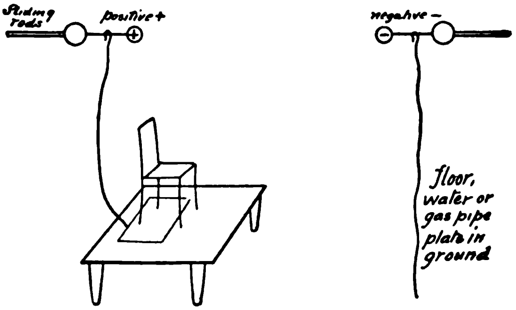

Fig. 40.—Static insulation or static bath.

The insulated platform is connected with a brass rod, known as a shepherd's crook, to the positive pole of the static machine. The negative pole is grounded by simply dropping a chain from it to the floor. Some prefer to have a metal plate, which is connected by a wire to a water-pipe or gas-pipe, and if these are not convenient, then the wire is continued outside of the house and connected with a large metal plate placed 4 or 5 feet under ground.

Synopsis of Modes of applying static electricity in medicine.[1]

General Applications.	Convective	Electrostatic or franklinic bath.	Electropositive. Electronegative.		
		Concentric franklinization (Breitung system).	Electropositive. Electronegative.		
		Static or franklinic autoconduction.	Franklinic or static undulatory direct current. Franklinic or static undulatory induced current.		
		Static or franklinic autocondensation.	Undulatory direct current. Undulatory induced current.		
	Conductive	Morton's wave current or static or franklinic undulatory inductive (1881) (hertzian franklinization).			
		Morton's modified monopolar undulatory current (called also Snow's wave current).			
		Derived franklinic or static induced current (Sheldon) or derived Morton wave current.			
	Disruptive	Werber's modification of Morton wave current (1902).			
		Indirect franklinic or static discharges by means of a detonator, and of water contained in a bath-tub, in which the entire body is plunged (general hydrofranklinization).			
Local Applications.	Disruptive	Sparks applied by means of electrodes of metal, wood, or hard rubber; spheric or pointed.	Applied at a certain distance from the body. Applied directly on different regions of the body covered by the clothing (electric massage).		
		Aigrettes.			
		Static or franklinic discharges by means of a spark-gap or through the intermediary of a spark-gap and water in a tub, into which a hand, arm, or leg is plunged (local hydrofranklinization).			
	Convective	Effluve	Applied by means of an electrode of metal or wood.	With one or more points.	For the head (static head breeze or bath). To any other part of the body.
		Discharges of Morton wave currents applied by means of glass vacuum electrodes.			

The sliding rods are separated as far as possible. The strength of current can be increased by placing a metal plate on the platform and then placing the legs of the chair on this metal (Fig. 41).

The current can be still further increased by placing the chair so that the patient can rest his feet on the metal plate. (See Fig. 42.)

The only difference between the connections for static insulation

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[1] Slightly modified from Virgilio Machado's table. Les applications directes de l'Electricité á la Médecine et á la Chirurgie, Lisbon, 1908.

and the Morton wave current is that the balls A and B are widely separated in static insulation, whereas in the wave current they are placed in contact to start with. The strength of the current used for static insulation is regulated mainly by the speed at which the machine is operating. This method of application is generally used when the case is hypersensitive to any form of electricity. It has a general quieting effect on the nerves, and is one of the best ways to begin static treatment, as by means of it you are sure to gain the patient's confidence. It does not produce the slightest shock, and can be used in the most sensitive cases.

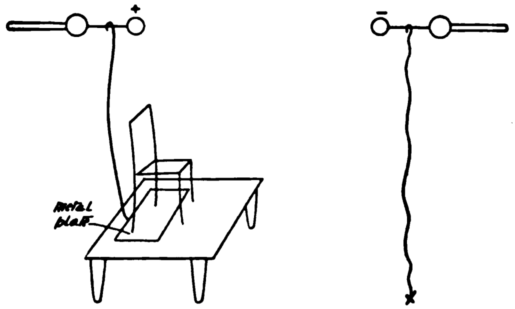

Fig. 41.—Legs of chair on metal plate.

The static bath is said to be electro-positive if the positive pole of the static machine is connected with the insulated platform.

The *application of the static induced current* from a machine of this type is made by adjusting the handle at "induced." There is no connection between the external coats of the two jars, the connecting rod being pushed under the machine.

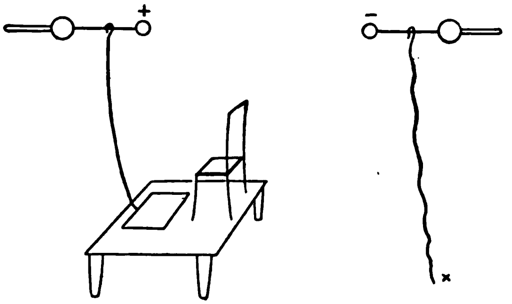

Fig. 42.—Patient's feet on metal plate.

The smallest Leyden jars, not much over an inch in diameter, are placed upon the little shelves, and their inner coats are connected with the prime conductors. Insulated conducting cords are fastened to the two binding posts, and lead to electrodes applied to the patient. It is not necessary, but customary, for the patient to be upon an insulated platform unless there is some contra-indication, like the simultaneous application of some other form of treatment, such as vibration. The machine should have been charged before the connections are made with the patient, and is now set in operation with the discharging rods in contact. These are carefully separated to an extent that is regulated by the sensation of the patient, but which will rarely be found to be greater than ⅛ inch, or 3 millimeters. This separation should be made gradually, and care should be taken not to allow the discharging rods to get too far apart, either as they are being adjusted or afterward, from the motion or vibration of the whole machine. An arrangement is provided in some machines whereby a screw-thread on the discharging rods is brought into play to produce accurately graded motion of the rods as they are separated, and to hold them in that position. The electric currents sent through the patient in this way have been explained elsewhere (page 27).

Fig. 43 shows the smallest Leyden jar connected to one pole of the static machine, and connected with the outside of this jar is an ordinary sponge electrode. The electrode is placed in position and the current regulated by slowly separating *a* and *b*. If a stronger current is desired, then two jars can be used as in Fig. 44, regulating in the same manner. The larger the jars used, the stronger will be the current with the same spark-gap.

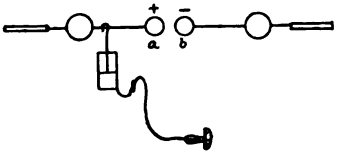

Fig. 43.—Static induced.

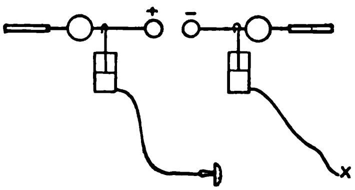

Fig. 44.—Static induced, intensified.

Here again, as in the wave current, it is essential to have a perfect contact between the electrodes and the patient. A single electrode can be used or two, as in Fig. 45, and any electrodes that is used with the galvanic or faradic current can be used with the static induced. As a rule, the smallest Leyden jars are used.

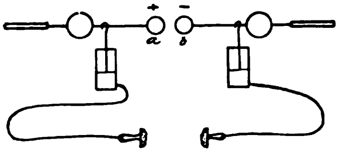

Fig. 45.—Static induced, intensified with two electrodes.

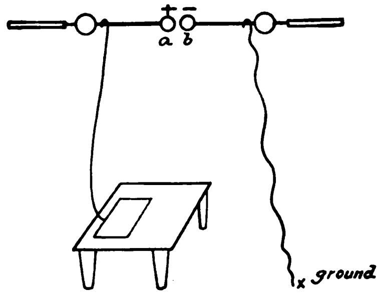

Fig. 46.—Morton wave current.

Static Wave Currents.—*The Static Wave Current.*—This is also known as the *convective discharge current*, and sometimes as the *vibratory current* or the *Morton wave current*. In this method the metallic plate of the platform is connected to the positive pole of the static machine, the negative pole being grounded, the sliding rods in contact. The patient is placed on the platform, having the feet on the metallic plate (Fig. 46). The strength of the current is now regulated by slowly separating *a* and *b*, and it is always well to withdraw the *negative* sliding rod. If the patients complain that they feel sparks on their feet, then remove the shoes, as this current should not be painful; if it is, it indicates a poor contact between the metal plate and the patient.

The strength of this current is regulated by slowly separating *a* and *b*. There must be a continuous spark between *a* and *b* when this current is properly used. Instead of applying the current through the feet, as above described, any electrode that is used with the galvanic or faradic current can be used in place of the metal plate. This current is not painful, and should not be used strong enough to produce any unpleasant effect upon the patient. Its main therapeutic value is due to the fact that it stimulates the glandular system to increased activity. It also has a local action in relieving the pain of sciatica.

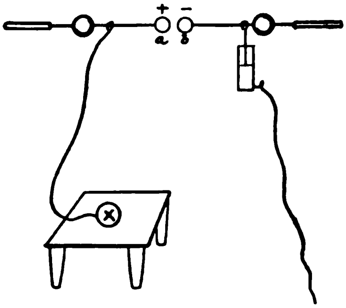

Fig. 47.—X represents any electrode that can be used with galvanic or faradic current.

A modification (Fig. 47) consists in interposing a large Leyden jar between the ground connections and the negative pole of the machine. The advantage of this method will be appreciated during the summer months; when the connection is made according to Fig. 46, it may only be possible to obtain a spark between *a* and *b* of 2 or 3 inches, while with the connection as per Fig. 47 it may be found that it is possible to obtain a spark 7 or 8 inches long.

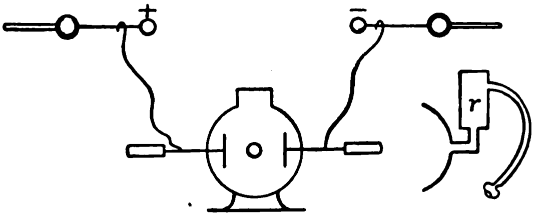

Fig. 48.—Ozone generator: *r*, Receptacle for cotton and medication.

The same method may be applied through a rectal electrode, using any electrode that would be used with the galvanic or faradic current.

Fig. 48 shows an ozone generator. Fig. 49 shows a further modification, consisting of an ozone generator in which the spark-gap takes place. Connected with the ozone generator is a tube, so that while the patient is having the wave current he is also inhaling ozone at the same time. This makes a very successful treatment for chronic bronchial troubles.

When used for this purpose, instead of *a* being connected with the metal plate on the platform the patient has a large metal plate on the chest. This may be in the form of tin-foil, such as is used for protection against the *x*-ray, or it may be a large pad electrode which has been made thoroughly wet.

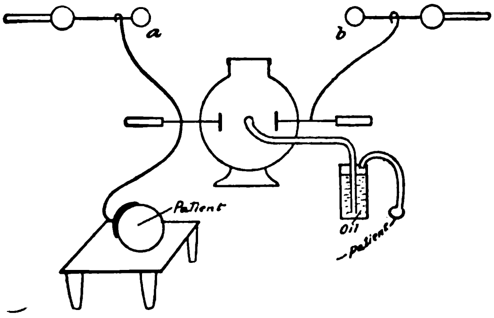

Fig. 49.—Wave current and ozone inhalations.

Connected with the ozone generator is a piece of soft-rubber tubing having a mouth-piece, so that the patient inhales the ozonized air at the same time the wave current is being passed through the chest. This can be modified in a number of ways. Instead of using a wave current, the *d'Arsonval high-frequency current* can be passed through the chest and the Tesla current applied to the ozone generator. In place of supplying ordinary atmospheric air to the generator, pure oxygen can be supplied, in which case the patient will inhale pure ozone. Again, the ozonized air can be compressed and used to operate a nebulizing device, in which case various medicated oils are used.

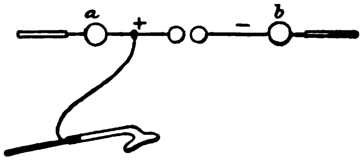

Fig. 50.—Wave current applied by vacuum tube.

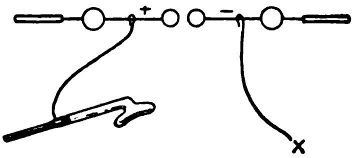

Fig. 51.—Wave current applied through vacuum electrode; other pole grounded.

Fig. 50 shows one way of using the ordinary *vacuum tube* with the static machine. The current is really nothing but the wave current applied through a vacuum electrode. The strength of the current is regulated by separating *a* and *b*.

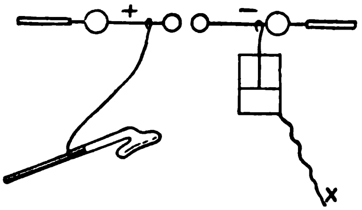

Fig. 52.—Wave current through vacuum tube; other pole grounded through Leyden jar.

Fig. 51 shows another way of using the vacuum electrode, which consists of grounding the negative pole and attaching the vacuum electrode to the positive pole. This makes the current stronger.

Fig. 52 shows similar arrangement with a Leyden jar which is suspended from the negative pole and which has its external armature grounded. While the current passing through the vacuum tube causes a violet color, this is not what is understood as high-frequency current or as the ultraviolet ray.

The Electric Connection for the Static Induced Current and the Static Wave Current.—The different contacts past which the discharge has to flow to the patient should be perfect. The Leyden jars may generally be hung upon the brass rods and produce a good enough contact by their weight; but the terminals of the conducting cords had better be secured by thumb-screws instead of being simply slipped into the binding-posts. Then, again, the fastening of the conducting cords to the electrodes should be by means of a thumb-screw or pressing the terminal of the cord into a spring slot, not merely by twisting it around some part of the electrode. The two terminals of the conducting cord, if they are, as usual, separate pieces of metal, should be soldered to the end of the wire. Simply twisting the wire about the metal terminal will not do so well. At all these points of contact particles of dust between the metallic surfaces or a film of metallic oxid upon one or both surfaces will make the contact imperfect and prevent the flow of a uniform current. The electrodes themselves should be considered. The ordinary sponge electrode usually has a perfect metallic connection from the conducting cord to the metallic surface, over which the damp sponge is stretched. At this point, however, an imperfection often develops in the shape of a layer of verdigris or other metallic salt upon the surface covered by the sponge. This interferes very much with the flow of the current. The result of an imperfect connection at any point is to increase enormously the resistance to the flow of the current, and consequently to make the current much weaker. Then every little while the current finds an unobstructed path and a strong current flows for an instant, to be again reduced as the oxid re-forms. The result is a series of disagreeable jerks of the different muscles of the part of the body to which the current is applied.

Block-tin Electrodes.—Pure tin is as flexible as sheet lead and does not rub off on the skin and clothes. Pieces of appropriate size are preferable to wet electrodes for many static applications.

Static Spark and Breeze Applications.—With the same connections the patient will receive a spark from a metal ball electrode and a breeze or effluve or spray from a pointed one. A shepherd's crook conducts the electric charge from one prime conductor of the static machine to the insulated platform upon which the patient sits; while a chain conducts the charge from the other terminal to the crown or some other effluve if a breeze is to be applied or to a ball electrode for applying sparks; or, the other prime conductor may be grounded, and indirect sparks may be drawn from any portion of the patient by bringing a grounded ball electrode near the surface. Another form of indirect spark is applied to the patient seated upon an insulated platform, connected with one prime conductor, while the electrode connected with the other prime conductor is approached not to the surface of the patient, but to a metal plate, rod, or ball, in close contact with the surface. The effect from this form of application is more like that of the static induced current or the wave current than of the spark.

Indirect Spark or Breeze.—The patient is seated upon the insulated platform, to which the shepherd's crook conducts the charge from the positive pole of the static machine. The negative pole is grounded and the electrode is also grounded. For the overhead indirect breeze, for instance, the crown is placed in the standard and raised above the patient's head (Fig. 53).

Friction Spark.—Connections are made as shown in Fig. 43, which is just the same as the direct method, the only difference being that the roller electrode is used and pressed firmly against the clothing of the patient. This is a very severe method of treatment. .

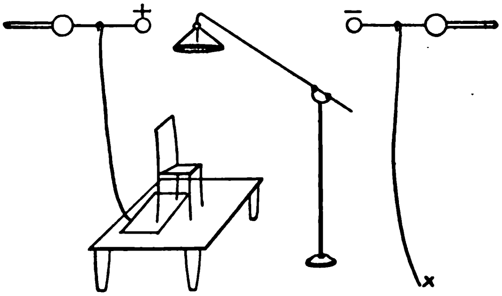

Fig. 53.—Indirect method, head breeze.

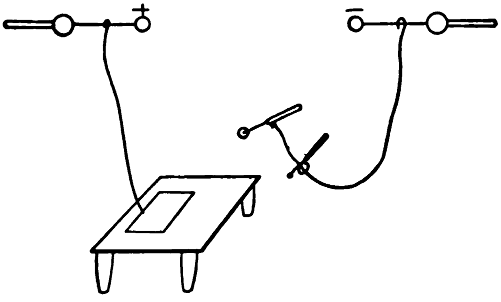

Fig. 54.—Direct method of applying static breeze or spark.

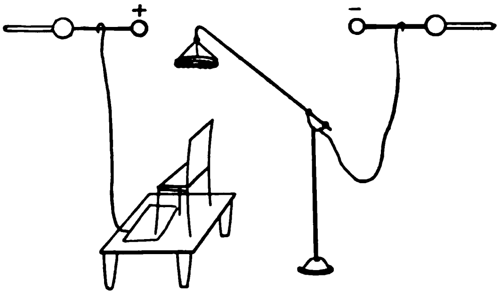

Fig. 55.—Direct head breeze.

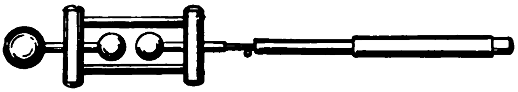

Fig. 56.—Electrode for indirect spark effect (Radiguet and Massiot, Paris).

Indirect Spark Electrode.—Fig. 56 illustrates a method of directing the static spark to any particular part. It consists simply of two brass balls joined together by a brass rod and held by a piece of hard rubber at an adjustable distance from the metallic part of the electrode handle. The terminal brass ball is pressed firmly against the part of the body to which it is desired to direct the spark. A continuous series of sparks may be applied by connecting the metallic part of the electrode handle with one pole of the static machine. Or separate sparks may be applied, by approaching a ball-electrode from the static machine and allowing a spark to pass from it to the metallic part of the electrode handle and thence to the terminal ball and the patient.

Direct Breeze Application.—The connections are the same as for the direct spark, but the electrode is a pointed one, and may consist of metal or carbon for the stronger or of wood for the weaker effects. The direct head breeze is one of the most useful of these applications. The crown is at a considerable distance from the patient's head to avoid uncomfortable prickling. The current will be in the form of a spark if a metal ball electrode is used. Other electrodes intended for a breeze or spray are illustrated on pages 41 and 42. The only difference in this method from the previous one is that an electrode is added, making a local application of the current instead of a general application. The chain to which the electrode is connected can be dropped on the floor or connected to the gas-pipe (Fig. 57).

With this method any style of electrode may be used. In a general way the strength of the current is governed by the material of which the electrodes are made, wooden electrodes giving milder effects, pointed metal electrodes giving a stronger effect, and, where a spark is desired, the large brass ball is usually used. This method is used for producing local action of the static current, a strong breeze being used in the treatment of mild muscular pains, such as come from catching cold. A static spark is used up and down the spine in cases of locomotor ataxia and for acute muscular pains. In acute muscular pain it will give almost instant relief. Of course, the pains come back again in the course of a few hours, but can be again relieved and for a long time. It also considerably relieves the ataxic pains. For administering the breeze, electrodes have been made of various materials, different kinds of wood varying in the current according to their resistance. There are some hollow electrodes in which have been placed various kinds of liquids.

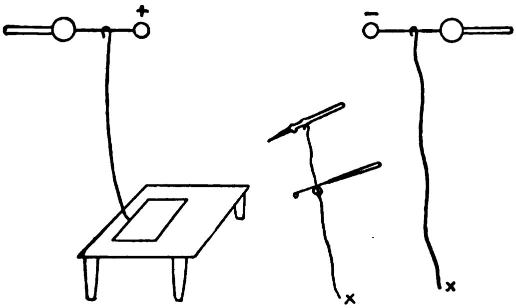

Fig. 57.—Indirect method of applying the static breeze or spark.

Indirect Spark and Breeze.—The patient is seated upon the insulated platform, to which the shepherd's crook conducts the charge from the positive pole of the static machine. The negative pole is grounded and the electrode is also grounded. For the overhead indirect breeze, for instance, the crown is placed in the standard and raised above patient's head (Fig. 53).

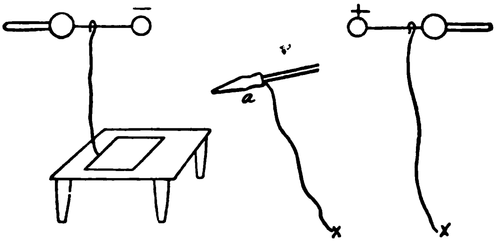

Fig. 58.—A hollow wooden electrode filled with liquid for long spray.

Fig. 58 shows the use of a *hollow wood electrode* filled with water. This affords a means of applying a spray of long, thin, painless sparks.

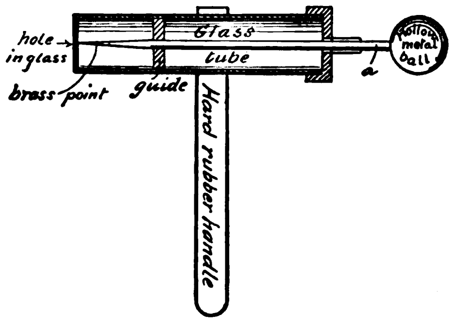

Fig. 59.—Spray director, *a*, can be moved to regulate distance between point and hole in glass.

Fig. 59 shows the *author's indirect spray electrode* with regulator. Fig. 60 shows the method of application.

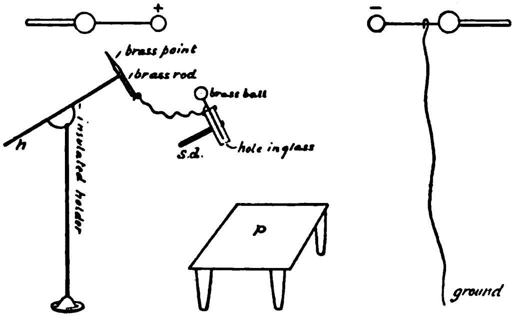

Fig. 60.—Method of applying spray director: *S.d.* is spray director held in hand of patient. Brass ball is connected to end of brass rod mounted on insulated holder, pointed end toward + pole of static. Strength of spray from director increased as brass point approaches + pole of static. (Original regulating device by author.)

Production of d'Arsonval Currents.—Fig. 61 shows the arrangement for securing *d'Arsonval high-frequency currents* from a static machine.

S, *s*, represent the sliding rods of a static machine; *g*, represents a spark-gap mounted in a box so as to obviate the noise; *l*, *l*, represent two Leyden jars; *a*, represents a hard-rubber tube; *c*, represents two binding posts connected with the end of the coil, which connects the outside coatings of the Leyden jars; *b*, represents the terminal of the fine coil winding, which is inside of the hard-rubber tube *a*.

The above is the outline construction of what is known as the *Piffard hyperstatic transformer*. It differs from the transformer as made by Tesla in that in place of the insulating tube *a* Tesla uses an insulating oil, which was required owing to the extremely heavy currents that he used, whereas for medical work the oil insulation is not required.

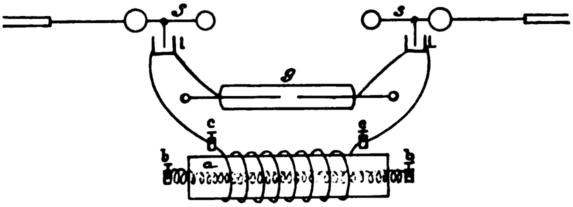

Fig. 61.—Arrangement for securing d'Arsonval high-frequency currents from static machine.

THE DOSAGE OF STATIC ELECTRICITY

When the patient is upon the insulated platform, which is connected with one pole of the static machine, the surface of the body in general is uniformly charged with electricity. The density of the charge depends partly upon the efficiency of the static machine and partly upon the completeness of the insulation.

The **Franklin** has been proposed by Benoist as a practical unit of density of the static charge.

The **C. G. S. unit** of electricity is a quantity of electricity which, concentrated at a distance of 1 centimeter from an equal quantity of the same polarity, will repel it with a force equal to 1 dyne. The latter is about equal to 1 milligram. A coulomb is equal to 3×10^9 C. G. S. units, and is a unit upon which the amperes and volts of electric current are based, but is entirely too large a unit to use with static electricity. The name Franklin is given to the small C. G. S. unit, and the dose of the static bath is expressed as being 10 Franklins when the density measured upon either surface of the hand is equal to 10 Franklins per square centimeter.

Benoist Electro-densimeter.—This consists of a delicate electroscope, which is charged by an insulated disk of appropriate size, which is applied to the patient's hand and then to the charging rod of the electroscope. The graduation upon the instrument should be such that the figures indicate so many Franklins per square centimeter of the surface tested.

PHYSIOLOGIC AND THERAPEUTIC EFFECTS OF STATIC ELECTRICITY

The effects of its application to the human body are muscular contraction, relaxation of muscular spasm, nerve stimulation or sedation, and similar effects upon glandular and circulatory functions and upon the intimate tissue processes, osmotic and others, of the body, and besides electrolysis and cataphoresis.

A person connected with one pole of a static machine does not remain charged with electricity as long as the machine is in operation, unless the person is insulated. The whole current is unidirectional, and contact with the earth prevents its accumulation as an electric charge. The conditions are quite different from those prevailing with high-frequency discharges, which are oscillatory and keep the patient constantly charged with one or the other polarity.

A person may be charged by induction from a static machine only if he is within a very few inches of it, but not if he is yards, or even miles, away, as with some high-frequency apparatus.

The production of heat in the human body is increased during and for some time after a treatment by static electricity (Pisani and Montuoro).

Tissue changes and glandular secretions are increased.

Sedative effects are obtained from a static bath or insulation, and from a static breeze applied exclusively to the part affected, as in neuralgia. Static baths are used, for instance, in neurasthenia, insomnia, and hysteria.

Stimulative effects are obtained by the static breeze and sparks, and the patients are generally benefited by the static bath in addition. Cases of hysteric neurasthenia and muscular weakness from rheumatism or diabetes are examples.

Physiologic Effects of Static Electricity.—Adopting Machado's classification (page 400) the effects of static electricity may be grouped as follows:

General stimulation, produced especially by local or general disruptive discharges.

Motor stimulation, produced by local disruptive discharges and the various wave currents. It is not so characteristic of static as of galvanic or faradic electricity, and the great majority of static applications are not accompanied by muscular contraction. Static sparks produce contraction of the voluntary muscles, and will do so even in some cases where other forms of electricity fail to act. During a treatment by static electricity the myograph shows that the muscles are able to resist fatigue longer than usual (Caprioti, Pisani, and Schnyder).

Static electricity stimulates the growth of young animals (Capriati's experiments on tadpoles and Piccinino's on silkworms. The latter grow faster and better when exposed to static electricity than under the influence of high frequency and autoconduction).

Sensory stimulation, producing the sensations of taste, smell, sight, touch, and hearing. Static sparks are not, however, so effective upon sensory nerves as high-frequency sparks. The static breeze applied to the head often flattens the hair down on the head and causes prickling, which may be intolerable if the current is too strong.

Revulsive and derivative effects and *counterirritation* produced by static sparks.

Vasodilatation, a secondary effect of static sparks. Locally, there is pallor followed by redness. Static applications, general or local, do not have a very marked effect upon the circulation in health, but they often produce a favorable effect in morbid conditions with excited action and elevated or depressed arterial tension.

Resolving and stimulating absorption of exudates are effects produced by static sparks and the different wave currents.

Excitonutritive and general or local tonic effects are produced by static insulation and by various wave currents and the static breeze, and by the current from a vacuum electrode connected with one pole of a static machine.

Stimulation of the natural means of defense of the organism is produced by the same conductive and convective applications.

Sedative effects, local or general, are obtained from a static bath or insulation and from a static breeze or effluve applied directly to the affected part. The wave currents also have this property.

The *hypnotic* effects of static electricity, or rather its effect upon the causes of insomnia, are produced by static insulation with a head-breeze. But excessive or too prolonged stimulation of muscular contraction by the wave currents will cause insomnia.

Cauterization.—Seated upon an insulated platform and holding the index-finger toward the crown furnishing the head-breeze, a short spray of violet light, hardly more than a bright point, may be seen to emanate from the tip of the finger-nail. The author has allowed this to continue for a minute or two and has found the finger-nail burnt or charred. While he has never heard of a patient's clothing taking fire from a static application, it has always been a matter of wonder to him that powerful sparks applied through delicate fabrics do not set fire to them; and he always holds himself in readiness to turn off the electricity and clap his hand over the ignited part if such an event should take place. The same sparks passed through a sheet of writing-paper produce perforations, which may be seen if the paper is held up to a bright light. The interstices in ordinary fabrics, however, probably allow of the passage of the static sparks without any effect on the cloth.

Therapeutic Indications of Static Electricity.—A study of the physiologic effects and the forms of static electricity employed to produce them, will at once suggest a wide range of general and local morbid conditions in which this treatment will be beneficial.

Static electricity in nervous diseases is grouped with electrical applications in a separate chapter upon electricity in diseases of the nervous system.

The following paragraphs are based upon Machado's classification:

As a *general stimulant* static electricity is invaluable in cases of debility following a prostrating illness, or prolonged work and anxiety, as after the illness and death of some close relative. The author employs positive insulation with a negative head-breeze for about fifteen minutes, and then applies about 12 sparks along the spine from a metal ball. The treatment is given three times a week and the effect is very prompt.

The same application is useful in depressed cardiac action and low arterial tension from any cause; and in sexual impotence the author has known of several remarkable cures in which the psychic element may have been predominant.

Static baths or insulation are valuable as a systemic treatment in pruritus and eczema.

Static baths or insulation are useful in *neurasthenic* patients with *obesity.*

The *excitomotor* effect of the disruptive discharges and of the different wave currents may be an element in the benefit from the latter in the treatment of *prostatic hypertrophy* and chronic *inflammatory uterine* and other pelvic conditions. Cases of *chronic constipation* are sometimes benefited by static sparks applied to the iliac regions.

Muscular contractions as a separate effect, either diagnostic or therapeutic, are more often secured by galvanic or faradic currents with or without condensers.

The excitomotor effect of the static wave current applied over the suprapubic region is useful for incontinence of urine due to insufficient control of the sphincters. Static sparks and effluves benefit atony of the unstriped muscle of the intestinal wall and pelvic viscera.

The *revulsive*, *derivative*, and *counterirritant* effects of the static sparks are employed in the treatment of acute muscular pain, which is often relieved at once, and on its recurrence may be relieved again for a longer time. The lightning pains of locomotor ataxia may also be considerably relieved. Chronic painful articular conditions from gout, rheumatism, and gonorrheal arthritis have been treated by static sparks, but the patients often complain and the author does not employ this method to any extent. Friction sparks from a roller electrode or from a ball electrode rubbed quickly over the surface outside of the clothes is an effective but very severe treatment for acute cases of stiff-neck and other painful muscular inflammations.

This action explains the benefit from *static induced currents in the treatment of furuncles*. The external armature of one Leyden jar of the static machine is grounded, while a wire from the other leads to a condenser electrode which is applied to the surface of the boil. This electrode may be made extemporarily by stuffing a glass test-tube with tinfoil. The effect may be to prevent suppuration, just as chemical counterirritants will often do, or, if pus is already present, the application will often relieve the inflammatory symptoms and favor evacuation.

The *static breeze* is of service in *erysipelas*, *suppurating wounds* and *contusions*, and *ecchymoses*. The static breeze is also an excellent application in *skin diseases of a neurotic origin*, and in pruritus vulvæ. It is of service in *synovitis*, the patient being in negative insulation, the positive pole of the machine grounded, and a wood electrode or an ordinary whisk-broom grounded separately.

The *revulsive* and *derivative* effect of the static wave currents with a moderate excitomotor effect are applied through a vaginal or a rectal electrode in pelvic disorders characterized by hyperemia. Such conditions are salpingitis without suppuration, subinvolution, endometritis, dysmenorrhea, retroversion due to enlargement of the uterus, and delayed menstruation (M. L. H. Arnold Snow, Static Electricity in Gynecology).

Synovitis is treated by the positive wave current, applied for twenty minutes from a large metal or kaolin electrode accurately fitting the joint (Humphris).

Static Electricity in Circulatory Disorders.—There is often an effect upon the circulation, and Luzenberger[1] has noted a sedative effect in patients with heart disease from a series of static treatments, and has also seen the cessation of mitral murmurs of spasmodic origin if the static breeze is applied to the precordia for ten minutes. Arterial hypertension is frequently reduced (Luzenberger), and static electricity is also an excellent application for arterial hypotension.

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[1] Arch. d'elect. med., August 25, 1905.

My own observations show that for conditions of low arterial tension and feeble heart the best applications are those in which the patient receives a disruptive discharge, or one through the air, sparks, and effluves. And for high arterial tension, the applications in which the patient is directly or indirectly connected with both poles of the static machine are indicated, although not as effective as high-frequency currents if high arterial tension is alone to be combated.

The *excitonutritive* and *tonic* effects are made use of in *diabetes*, where the results are often wonderfully good, and in *oxaluria* and uricacidemia. Cases of deficient glandular secretion are benefited, such as hypochlorhydria and anachlorhydria and deficient intestinal secretion. The best method is to apply the static breeze or brush discharge over the abdomen without sparks.

Rheumatoid arthritis treated by static electricity: the wave current may be applied, and the machine should be powerful enough to give a 10-inch spark-gap with an electrode of 150 or 200 square centimeters. Other cases require the static indirect spark: negative insulation, sparks 4 to 8 inches long drawn from the patient's body by a grounded electrode, the poles of the static machine far apart. If the sparks are too painful, an indirect breeze may be applied or a wooden ball not too dry may be used instead of the metal-ball-spark electrode. The static treatment may be preceded by a local application of incandescent electric light.

Ionic medication is to be preferred where there is boggy swelling around the joint (page 401), and diathermy by high-frequency currents (page 70) is often of the greatest benefit.

Dyspepsia may be treated by the static wave current preceded by a sharp application of incandescent electric light, both over the upper part of the abdomen.

Lumbago is treated by the application of a 500 C. P. incandescent lamp for fifteen minutes; then the static wave current for the same length of time with electrodes 8 x 10 inches, and the spark-gap increased to tolerance perhaps 8 or 10 inches (Humphris).

Sciatica.—Find the small affected area by applying short sparks along the course of the nerve. A flexible metal positive electrode, a little larger than this area, is bandaged firmly. The negative pole is grounded and the spark-gap opened gradually, because the application is painful at first. Long-standing cases require the indirect spark. After the first three or four treatments combine the static electricity with 500 C. P. incandescent lamp (Humphris).

Gonorrheal Rheumatism Treated by the Static Wave Current Applied to the Prostate.—Titus applies the vacuum electrode connected with one pole of a static machine to the region of the prostate. This is on the theory that the gonococci are located in the prostate, and not in the joints, and that they are weakened and evacuated with the urine in consequence of the contractions of the prostate caused by the electric applications.

There are cases, however, where the gonococci are abundantly present in the pus which fills the joint, and where surgical evacuation and disinfection are required.

The use of bactericide applications to the deep urethra is the other alternative when the germs have not migrated to the articulations and the joint troubles are due only to toxemic products.

DYNAMIC ELECTRICITY

Dynamic electricity may be regarded as electricity in motion, while static electricity is electricity at rest. Dynamic electricity is known chiefly by the effect of its transmission through conducting paths, and static electricity chiefly by its effects as a stationary charge or as a disruptive discharge through non-conducting paths.

NATURE OF DYNAMIC ELECTRICITY

Electricity of all kinds is probably of the same essential nature. Dynamic as well as static electricity may be assumed to be due to the application of forces which disintegrate the atoms of matter and liberate a greater or less number of ions about $\frac{1}{1000}$ the size of atoms. The positive ions liberated are always equal in number to the negative ions. It is an interesting subject for speculation, whether perhaps the ions or the still smaller electrons are electricity and whether all matter is simply electricity under a variety of forms. By the application of some force, such as chemic affinity in the case of a zinc and a copper plate dipped into dilute sulphuric acid and connected by a wire outside of the liquid, a liberation of ions is supposed to take place. The force with which the positive and negative ions tend to pass through the different media so as to neutralize each other is called the electromotive force, and is measured in volts.

The natural and artificial sources of what is called dynamic electricity generate a very much greater quantity and at a very much lower pressure than is the case with the form called static electricity, and the production is usually continuous and more or less uniform. The distinction is not at all an artificial one; the very existence of static electricity implies a degree of insulation sufficient to retain the electricity until a high pressure has been produced; while with dynamic electricity the natural process is for it to have a conducting path along which it can flow as fast as it is generated. The flow of dynamic electricity takes place as naturally as the flow of water from a higher to a lower level, or as the movement of the water or the air when the hand is passed through it. Dynamic electricity is really akin to mechanic motion, while static electricity is equivalent to a tendency to motion produced by an elevated position. A force applied to a body and pushing or pulling it over a smooth surface at a uniform rate of speed is comparable to dynamic electricity, while the force which raises a body to a height

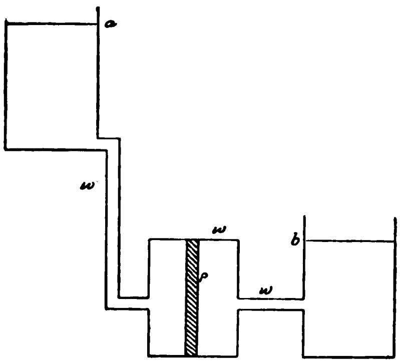

Fig. 62.—Comparison between electric tension and hydraulic pressure: *p*, Piston moving because of the difference in hydraulic pressure in reservoirs *a* and *b*.

from which it has a tendency to fall is representative of the force producing static electricity.

Fig. 62 shows another comparison between electricity and hydraulic power. The piston, *p*, moves in consequence of the pressure of the water in the cylinder, and is supposed to be connected with an engine so as to perform work. To do a specified amount of work or move a certain distance against a certain resistance requires a certain water pressure or difference in level between the water in the reservoir *a* than in the reservoir *b*, and also implies a flow of water through the tube and cylinder *w* as the piston moves forward. In such a case the tube and cylinder *w*, *w*, and *w*, by which the water is transmitted from the upper to the lower reservoir, presents a certain amount of frictional resistance, and a certain amount of work is expended in overcoming this. It makes no difference how much water is contained in either reservoir, provided it is at the required difference in level. The hydraulic pressure of a column of water so many feet in height may be compared to the electric tension or to a certain number of volts difference in potential. The frictional resistance in the tube and cylinder *w* may be compared to the ohmic resistance of the conducting wire, and in corroboration of the doctrine of the conservation of energy all the work so expended reappears as heat or light. The rate of flow of the water through *w* is comparable to the rate of flow or the amperage of the electric current. The work done in moving the piston *p*, and whatever may be attached to it is equivalent in our simile to the work done by the electric current in producing electric or magnetic induction, with or without motor effects, and various chemic, physical, and physiologic results.

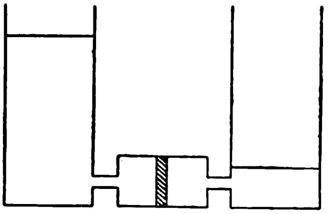

Fig. 63.—Comparison with hydraulic pressure. Work will be performed as the two levels become equal. Motion then ceases.

The rate of flow is increased by increasing the pressure (height of the column of water or number of volts difference in potential); by reducing the frictional or ohmic resistance, and by reducing the resistance to the motion of the piston *p*, or the amount of work to be performed by the current. To make the comparison with the case of two bodies charged to a different potential and then connected by a simple conducting wire we have merely to imagine that the piston *p* is left out and friction of the tube *w* is the only resistance to be overcome.

The diagram, Fig. 62, would be strictly comparable to the case of a constant potential electric battery if we should introduce a pump to transfer water from the lower to the higher tank, so as to maintain the two at exactly their original levels. In such a case there would be a uniform circulation of water through the apparatus, just as there is a uniform current of electricity through a battery and its circuit.

Two bodies which are charged to different electric potentials, but which are simply allowed to discharge by making an electric connection between the two would be represented by Fig. 63. Here there is a difference in level at the start, and the pressure of the water causes the piston to advance and the water to reach the same level in both cylinders. Then the pressure in each direction becomes equal and motion ceases.

SOURCES OF DYNAMIC ELECTRICITY

The production of electromotive force occurs in consequence of a very great variety of natural and artificial causes. Electric currents in useful amounts are generated by chemic action, by heat, by the motion of magnets or of coils of wire through which a current is passing. And every vital process in plants and animals and almost every other phenomenon in nature or art are productive of a demonstrable current. The mere contact of dissimilar metals produces such a current, and heat applied to the junction of two such metals forms the basis of a practicable type of electric battery.

THE VOLTAIC OR GALVANIC CELL

To understand the modern theory of dynamic electricity it will be useful to consider the case of a simple voltaic cell (Fig. 64), consisting of a jar partly full of dilute sulphuric acid in which dip a plate of zinc and one of copper. The two plates are connected outside of the liquid by a copper wire, which is a good conductor of electricity. The chemic action of the sulphuric acid upon the zinc produces an electromotive force which passes through the liquid from the zinc to the copper, and is continued through the wire outside of the cell from the copper to the zinc. This is taking the direction of the positive current as that of *the current*.

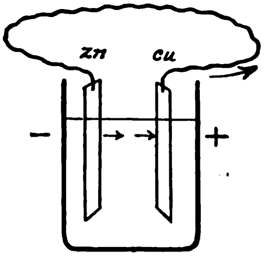

Fig. 64.—Diagram of simple voltaic cell.

The Theory of Arrhenius (1887).—In an electrolyte, *i. e.*, such a fluid as the dilute sulphuric acid in the battery which we are considering, the molecules contain two kinds of ions which are electrically associated with their respective electric charges before the generation of the electromotive force. The ions move about irregularly among the water molecules, sometimes approaching and sometimes receding from an ion of the opposite kind. When a difference of potential is established between the two electrodes by the chemic action of the acid upon the zinc, a directive influence is exerted upon all the free ions in the liquid and a general movement of ions in opposite directions takes place. The negative ions all move toward the zinc, and the positive ions all move toward the copper. It is not to be supposed that any individual ion moves the entire distance from the zinc to the copper or from the copper to the zinc. Any one ion may move only a short distance through the liquid and then become bound again. There is probably an interchange of ions all along the line, and the final result is the liberation of free molecules or radicles of an electropositive substance at one electrode and of an electronegative substance at the other. In the case of the voltaic battery which we are describing the electropositive substance which is liberated is hydrogen gas, and this makes its appearance upon the surface of the copper plate. The electronegative substance is the acid radicle SO_4, and this enters into combination with the zinc, forming sulphate of zinc. It is really the chemic affinity of the zinc for the acid radicle that has star ed the entire process, and many of the great physicists of the present day believe that chemic affinity is only a manifestation of electricity. The chemic change is noted only at the two electrodes. Throughout the rest of the liquid the changes which are going on are subatomic and produce no effect which can be recognized by chemic analysis. Associated with, and in consequence of, the movement of the two kinds of ions through the liquid there is a current of electricity through the liquid from the zinc to the copper, and this same current is continued outside of the liquid in the wire connecting the two electrodes. The current outside the liquid passes from the copper to the zinc, completing a circuit. If the two metals are not connected by a wire outside the liquid, in this particular case there will continue to be some action of the acid upon the zinc, and some liberation of hydrogen upon the surface of the copper, but these will not be nearly so vigorous as when the circuit is completed. Many voltaic cells are made up of electrodes and an electrolyte between which no chemic action takes place on open circuit, and in these, of course, it is not necessary to lift the electrodes from the liquid in order to prevent wasteful chemic action when the battery is not in use. This must be done, however, with the simple voltaic cell with zinc and copper elements and a sulphuric acid electrolyte. While the circuit is closed by the connecting wire outside the cell, chemic action goes on in the cell, and an electromotive force is generated or a difference in potential is maintained between the two metallic elements. In the simple voltaic cell just described the chemic action, and, therefore, the maintenance of the electromotive force, are liable to very serious reduction by polarization, interference due to the accumulation of hydrogen gas upon the surface of the copper plate.

Voltaic cells are made in which the action is uniform, and in such a cell an electric current continues to flow at quite a uniform rate until the zinc has been completely consumed by the acid or until the acid is all used up. The production of the electric current in such a case is analogous to the evolution of heat in consequence of ordinary combustion, and the quantity of electricity produced is proportional to the amount of zinc consumed. The current is of greater volume from a large cell with a large surface of zinc exposed to the action of the acid than from a small cell, but the potential or pressure or voltage is the same. The electromotive force, measured by the voltage, depends upon the difference in potential between the two elements. Two copper plates in dilute sulphuric acid would not produce a current, and neither would two zinc plates. Providing a suitable electrolyte is used, a zinc and a copper element will produce about 1 volt, while a cell in which the positive element is metallic mercury, and the negative element is zinc, and the electrolyte a paste consisting of mercurous sulphate in a saturated solution of zinc sulphate, produces an electromotive force of about 1.436 volts. The electromotive force determines the amount of electricity which a battery will force through a certain resistance. If the resistance of the human body under certain circumstances is 2000 volts, a single zinc-copper cell will send through the body only about $\frac{1}{2000}$ ampere, no matter how large the cell may be or how many amperes it may be capable of producing. When a battery is short-circuited, or the copper and the zinc are connected outside the liquid by a conductor with practically no resistance, the amount of current that will flow is proportional to the amount of zinc exposed to the action of the acid, and the larger the cell the stronger the current.

Voltaic Cells in Series and in Parallel.—When two or more cells are connected in such a way that all the copper plates are connected with one wire and all the zincs with another and the two wires can be brought together as the opposite terminals of the battery, the cells are said to be connected in parallel. The connection in series is made by connecting the zinc of one cell with the copper of the next, making a series of which one extremity is the zinc of the first cell and the other extremity is the copper of the last cell. The two battery wires pass from these two extremities.

A battery set up in *parallel or multiple* acts like a single cell with a large amount of zinc surface to be exposed to chemic action. The current produced is of the same large quantity as if the zinc surfaces in all the cells were added together in one large cell. If the battery is made up of twenty cells in parallel, and all of the same size, the current strength on short-circuit will be twenty times as great as with a single cell. The voltage, however, will be the same as would be produced by a single cell; and a very large number of cells connected in parallel will not send any more electricity through the human body than a few cells. A battery set up in parallel acts in all respects like a single large cell.

A battery set up in *series* behaves very differently. The amount of current on short-circuit is about the same as with a single cell, but the voltage is proportional to the number of cells. The current which it will send through the human body is proportional to the number of cells, and with a very large number dangerous shocks may be given. The electromotive force of all the cells is added together, while the quantity of electricity generated remains the same. On short-circuit the current will be no more with twenty cells in series than with a single cell, but when there is a certain amount of resistance in the circuit outside of the cell, the current which one cell will send through that resistance is less than on short-circuit. The current which twenty cells in series will send through a large resistance may be twenty times what one cell would send through the same resistance. Of course, the amount of current sent through the resistance is limited to the maximum output of a single cell in the case of a series battery.

The amount of zinc consumed is the same in both cases, and the same amount of power is generated. The difference between the two types of battery is analogous to that between two steam-engines consuming the same amount of coal, and producing the same amount of power, but one geared to move a heavy weight slowly, and the other to move a much lighter weight at a correspondingly rapid rate. In mechanic motion it is practically true that it takes the same amount of power to lift a body weighing one pound 100 feet, as to lift 100 pounds one foot; and the motion of the two bodies may be caused by suitable transformers to yield the same amount of power. In mechanics the unit of power is the foot-pound. In electricity it is practically true that the same power is required to produce a current of one ampere and ten volts as to produce a current of ten amperes and one volt. And by suitable transformers the same amount of power may be obtained from the two currents. The unit of electric power is the *watt*, or the volt-ampere. A watt is produced by a current of one ampere with a potential of one volt or by a current of smaller quantity and a correspondingly greater potential. Thus a current of $\frac{1}{10}$ ampere and 10 volts produces a watt. And, on the other hand, a larger current at a correspondingly smaller potential will produce a watt. In any case the number of watts is found by multiplying the number of amperes by the number of volts. The physical and physiologic effects produced by a certain amount of energy in the form of a current of high potential and low amperage are radically different from the effects of the same amount of energy as a current of low voltage and great amperage. In the case of the voltaic battery and of the generators of electricity known as dynamos the same amount of energy may generate a current of high voltage and small amperage or the reverse, according to the way in which the different elements are connected up. And in all these cases the current may be converted from one type to the other without material loss of energy by suitable apparatus.

From what has been stated, it will be gathered that not more than about one volt can be obtained from a single zinc-copper voltaic cell no matter what its size may be, and it is a fact that voltaic cells of all the different materials used as elements and electrolytes vary but little in the voltage produced by a single cell. This is never greater than about three volts. The amperage from a single cell has no such limitations. It varies with the size of the elements and the intensity of the chemic action between the electrolyte and the active element. The strength of the current, however, is regulated by the resistance it has to pass through, and this is made up of two factors—the resistance in the cell itself and the resistance in the conducting path outside the cell. When the external resistance is very slight, an increased surface of zinc obtained by the use of a single large element or several elements in multiple produces a corresponding increase in the current strength, because it reduces the internal resistance of the battery by increasing the area of cross-section of the conducting path through the electrolyte. The external resistance in this case remains the same, but we are supposing a case in which this is so small as to be insignificant. The same calculation will show that there is a limit to the current strength obtainable from a battery connected in multiple, for even when a large number of cells are used and the internal resistance becomes very small the voltage is not increased. When it is desired to secure a large amount of current through a large external resistance, a voltaic battery should be set up in such a way as to get the benefit of a large electromotive force and of reduced internal resistance. With a series battery, of course, the current strength is limited to the maximum output of a single cell; while with a simple multiple connection, the electromotive force, being only that of a single cell, will not force much more current through the large external resistance than the output of a single cell. To get the maximum current there should be the proper relation between the electromotive force and the internal and external resistances, and this is obtained when the internal and external resistances are equal. The cells may be connected in two or more parallel series, securing increased electromotive force and an internal resistance calculated to equal that of the external circuit. One case in which a large current is desirable is for use as a cautery and another is in electroplating. For both of these the efficiency is dependent upon the amount of current, and in both cases the external resistance is comparatively small. If a voltaic battery is used for these purposes, it should consist of a small number of large cells in series or of a number of parallel series of smaller cells. There should be such a number of these series that counting one cell of each series the zinc surface will be the same as in a single one of the larger cells. If this is the case, the number of cells in each series of the small cells may be the same as the number in the single series of the larger cells. When we come to the consideration of dynamic electricity produced by mechanic means, it will be seen that it is a very easy matter to regulate the relation between the quantity and the potential of the current at its very source, or to vary these relations afterward so as to adapt the current to various therapeutic requirements. For electric welding, where two pieces of metal are to be heated red hot, the ordinary electric current from a dynamo is changed by a transformer to one of only about five volts, but of several hundred amperes, while for use in actuating an *x*-ray tube the same current of 110 volts is transformed into one of perhaps 100,000 volts, and only a very few milliamperes, or thousandths of an ampere. It is perfectly practicable to transform the current from a voltaic battery into a current suitable for *x*-ray work. It is necessary that the battery should be sufficiently powerful, or should generate a sufficient number of watts. The coil or whatever kind of transformer is used does not add one particle to the power, but only changes its form just as a pulley does in the case of mechanic power. A battery of from thirty to sixty full-sized voltaic cells of any good type, such as the LeClanché or the Daniell, will give a sufficient current for an *x*-ray coil with a mechanic interrupter, but will not produce as powerful a ray as may be obtained from the 110-volt electric-light current generated by a dynamo. And while a much larger battery would perhaps do the same work as the electric-light current, it would cost much more. Accurate measurements have shown that the electric energy obtainable from a dynamo by the combustion of a ton of coal is six times that resulting from the consumption of a ton of zinc in voltaic batteries, and, of course, each ton of zinc costs a great deal more than a ton of coal. Voltaic batteries are desirable only for purposes requiring a portable outfit and a very small current, and that only for short periods of time, at not too frequent intervals. The small current makes the initial cost so small as to be less than it would cost to install the necessary appliances for the use of a current from a dynamo. And the short and infrequent periods of use keep the cost of maintenance within reasonable limits. In the author's experience, however, the electric-light current gives better results for all kinds of therapeutic work. It has been generally adopted wherever available.

The amount of work done in the form of heat-production is dependent upon the number of amperes of current passing through the circuit, and this can be regulated in two ways: in the case of a voltaic battery by using large cells or a sufficient number of parallel cells to produce the required amount of current, and adding cells in series with each of the parallel cells, making a number of parallel series producing the voltage necessary to send the necessary amount of current through the resistance of the circuit; with the electric-lighting current the regulation is accomplished either by the simple introduction of the necessary resistance in the form of a rheostat or by the use of a transformer. The rheostat adds its own resistance to that of the rest of the circuit, and the number of amperes which will pass through the circuit is found by dividing the number of volts (110) by the number of ohms resistance in the entire circuit. A shunt may also be used as a volt controller and the strength of current regulated in that way.

Maximum Efficiency.—The law that the maximum efficiency of a source of electricity is obtained when the external resistance is equal to the internal resistance of the generator is sometimes misleading in its practical application. In the first place, it does not refer merely to the intensity or volume or the number of amperes of the current sent through the external circuit. It refers to the total energy sent through the external circuit, or, in other words, to the number of watts, or the number of amperes multiplied by the number of volts. Ohm's law, $C=\frac{E}{R}$, can be applied to this case. C represents in a general way the number of amperes of current produced; E, the electromotive force, and R the resistance. But in the case under consideration the resistance is partly external and partly internal—in the generator itself. The equation reads $C=\frac{E}{R+r}$, where R is the external and r the internal resistance. When it comes to a consideration of the number of watts passing through the external circuit, *i. e.*, the useful power of the generator, we should have the equation $W=CV$, or the number of watts in the external circuit equals the number of amperes in the external circuit, multiplied by the number of volts difference in potential between the two poles of the generator. The number of amperes C is the same throughout the circuit, both in the external circuit and through the generator itself. The electromotive force of the generator produces the current C through the combined external and internal resistances R and r, and is greater than V, the difference in potential between the two poles of the generator which is sufficient to produce the same current C through only the external resistance, R.

There are two different conditions under which it may be desired to calculate the maximum current to be obtained from a voltaic battery or other generator.

In one case the internal resistance of the generator r and its electromotive force E are both invariable, while the external resistance R can be regulated. Suppose the electromotive force E of the generator to be 90 volts, and its internal resistance r to be 10 ohms, then the number of watts passing through the external circuit is greatest when the external resistance R is equal to the internal resistance r. This is shown in the following example:

$$W=\frac{RE^2}{(R+r)^2}$$

If R and r are each 10 ohms, and E is 90 volts, the equation would be—

$$W=\frac{10\times 90^2}{(10+10)^2}=202.5 \text{ watts.}$$

If R is 20 ohms and r 10 ohms, the equation is—

$$W=\frac{20\times 90^2}{(20+10)^2}=180 \text{ watts.}$$

If R is 5 ohms and r 10 ohms, the equation is—

$$W=\frac{5\times 90^2}{(5+10)^2}=180 \text{ watts.}$$

Another case is that of a generator whose internal resistance r is variable, but acting upon an external circuit like the human body with a large resistance R, which cannot be regulated. In this case the smaller the internal resistance r, the greater is the number of watts passing through the external circuit. This is shown in the following examples in the case of a generator producing an electromotive force E equal to 50 volts, and with an external resistance R equal to 1000 ohms.

If the external and internal resistance are equal, R and r are both 1000 ohms, and the equation would be—

$$W=\frac{1000\times 50^2}{(1000+1000)^2}=0.625 \text{ watt.}$$

It is manifest that in the equation $W=\frac{1000\times 50^2}{(1000+r)^2}$; the smaller the value that can be given to r, the greater will be the value of W. Thus, if the internal resistance r is 10 ohms, we have

$$W=\frac{1000\times 50^2}{(1000+10)^2}=24.5 \text{ watts.}$$

In the case of several generators, n, each of which has an invariable electromotive force E, and internal resistance r, formulæ may be calculated for their connection either in series or in parallel, or both combined to produce the greatest number of watts in the external circuit. This maximum is obtained when—

$$\frac{t}{q} = \frac{R}{r} \text{ or when } t = \frac{qR}{r} = \sqrt{\frac{nR}{r}}$$

t being the number of groups set up in series, and q the number of cells in parallel in each group.

If $R=r$, then $t=q=\sqrt{n}$, or if the external resistance is equal to the internal resistance of each cell, the maximum effect is obtained by making the number of cells in each series equal to the number of series, thus with 36 dividing them into 6 series of 6 parallel cells each.

If $R>r$ then $t>q$, or if the external resistance is greater than the internal resistance of each cell, the number of groups set up in series should be greater than the number of parallel cells in each group.

If $r>R$ then $t>q$, or if the internal resistance in each cell is greater than the external resistance, there should be a greater number of parallel cells in each group than there are of groups set up in series.

The following equations are examples:

1. In the case of a battery of 36 elements, each with an electromotive force E equal to 1.5 volts and an internal resistance r equal to 2 ohms, used for applying a voltaic current to the human body (with a resistance R equal to 1000 ohms), the equation would be $t=\sqrt{36\,\frac{1000}{2}}$ from which it is evident that $t>n$: to approach as near as possible to a maximum t should equal n, or the series number should equal the total number of cells. The entire 36 cells should be set up in series to send the greatest number of watts through the human body.

2. For electrolysis with a resistance R of 20 ohms the equation would be—

$$t = \sqrt{36\frac{20}{2}} = 18,$$

that is, there should be a series of 18 groups (each group containing 2 parallel cells).

3. For cautery with an external resistance R equal to 0.5 ohm the equation to produce the maximum number of watts in the external circuit would be—

$$t = \sqrt{36\frac{0.5}{2}} = 3,$$

that is, there should be a series of three groups (each having 12 parallel cells).

These facts have been further elaborated in an excellent article by Guilleminot (Arch. d'elect. Med., 1903).

Sparking Distance of Voltaic Batteries.—The sparking distance obtained from a voltaic battery increases in about the same ratio as the voltage, or a little faster. A battery of De la Rue chlorid of silver cells with a voltage of 1000 produces a spark about $\frac{1}{200}$ inch long; 5800 such cells spark across a space of $\frac{1}{17}$ inch; 11,000 such cells spark across a space of $\frac{2}{3}$ inch.

Thirty or forty voltaic cells in series will give not only a spark, but an arc between the bare ends of the two insulated wires if they are first brought together and then slightly separated. There is a certain amount of noise produced, and sufficient heat to vaporize particles from the two metal surfaces. If the individual cells are small, the amperage and the volume of the arc will be small; while if the cells are large or each member of the series is formed by a number of cells in parallel,the arc will give a powerful light and heat. There will be no tendency for the current to flash across any appreciable distance; the sparks are produced only after actual contact, and the thinnest complete layer of insulating material is sufficient for the conducting cords.

Polarization in a Voltaic Cell.—In a simple zinc-copper cell with a 10 per cent. sulphuric acid electrolyte the current very soon becomes weak on account of the deposit of bubbles of hydrogen gas upon the surface of the copper. The gas has very great resistance to the passage of electricity, and reduces the current strength proportionately. Hydrogen gas is electropositive to zinc, and so a counter electromotive force is generated which reduces the direct current strength. This rapid diminution in the strength of the current is not of serious consequence in cases where the current is to be turned on for only short periods, as for ringing an electric bell or for cautery purposes. It is known as polarization, and immediately ceases when the current is turned off and the bubbles of hydrogen escape. One way of preventing polarization in a voltaic cell is by turning the current on and off frequently. Another way is by the use of some depolarizer surrounding the copper, like nitric or chromic acid, which has a strong affinity for hydrogen and prevents its being deposited upon the surface of the copper. Another way is to have the copper immersed in some fluid, which will deposit not hydrogen, but some good conductor, like metallic copper, upon the surface of the copper. A solution of sulphate of copper is used in one of the best two-fluid cells. The zinc is in a solution of sulphate of zinc and the copper in a solution of sulphate of copper; the two solutions being in electric connection through the porous wall of the jar that separates them. In this case the substance deposited upon the copper plate is metallic copper, which aids rather than impedes the current. No cell in which polarization is not provided against is suited for regular electrotherapeutic purposes.

Local Action in a Voltaic Cell.—A piece of pure zinc, such as may be obtained by distillation, is not affected by 10 per cent. sulphuric acid if dipped into it alone or with a piece of copper, unless the external connection is made which permits the electric current to flow. And in a battery in which the zinc was absolutely pure, the consumption of the zinc would cease while the current was turned off by opening the external circuit, even though the zinc and copper still remained in the dilute acid. With ordinary commercial zinc this is far from being the case. The zinc continues to be acted upon even on open circuit. This is due to particles of impurity in the zinc, each particle forming a voltaic couple with the neighboring portion of zinc, and setting up an electric current with an accompanying consumption of zinc by local action. No effect is produced upon the copper plate. This same local action also occurs during the use of the battery. It causes a waste of zinc while the battery is in operation, and renders it necessary to lift the metals from the acid when the current is turned off. An extremely simple means of preventing local action consists in amalgamating the surface of the zinc by coating it with metallic mercury, and quite recently a manufacturer in Rhode Island has been able to melt zinc and mercury together in such a way as to make a complete mixture of the two through the entire mass of the zinc. Amalgamation removes the impurities and leaves the surface of the zinc covered with a liquid layer of pure zinc dissolved in mercury. Zinc so prepared is as free from local currents as if it were a plate of chemically pure zinc. It is not affected by the acid while the current is turned off, and there is no useless consumption of zinc while the battery is in operation. An easy way to amalgamate zinc is to dip it in hydrochloric acid, and after drying it, to rub a few drops of mercury over its surface with a cloth. In the case of a cell in which the zinc is not amalgamated, the local action which takes place on open circuit, *i. e.*, when the wires are disconnected, is seen only at the surface of the zinc, where a consumption of the metal occurs and there is a liberation of hydrogen gas. The power generated by the consumption of the zinc on open circuit is wasted as heat, the temperature of the acid rising in proportion to the activity of the effect upon the zinc.

The Component Parts of a Voltaic Cell.—A voltaic cell consists of two plates of different metals or a metal and some other substance, called *elements*, and forming a voltaic couple which are dipped into a suitable fluid called an *electrolyte*, and give rise to an electric current when their ends above the surface of the liquid are connected by a conductor of electricity.

The elements forming a voltaic couple may be two of the ordinary metals or a metal and carbon or two liquids or even two gases. For practical purposes the elements are always of the first two classes. The electrolyte is almost always a liquid, and must conduct electricity and be decomposed by it. The ends of the elements which project above the surface of the liquid are called the *poles* or *electrodes*, and to them are attached the conducting cords.

Only one electrode is acted upon by the electrolyte when the circuit is closed. This is the case no matter what an affinity the electrolyte may have for each of the electrodes separately. The electrode which is acted upon is always the electropositive one; thus, in the case of the zinc and copper couple in dilute sulphuric acid, only the zinc is acted upon, and eventually the zinc is entirely consumed and the acid changes to a solution of sulphate of zinc. If, on the other hand, the two elements had been copper and graphite, the copper would have been the electropositive element and would have been the one to be acted upon. Any metal in the electromotive series[1] is electropositive in relation to a metal occurring later in the list. The direction of the current through the electrolyte is from the electropositive element to the other. This is the direction of the positive current. Outside of the liquid, however, the positive current is continued from the copper to the zinc, so that the copper forms the positive pole of the battery and the zinc the negative pole. This is a little bit confusing, but it is none the less the fact that the electropositive element forms the negative pole of the battery as far as the external circuit is concerned.

When the two poles are connected outside of the fluid by being touched together or by a direct conducting cord with practically no resistance, the battery is said to be short-circuited, and the maximum possible current will flow. Some batteries give a very strong current on short-circuit, and rapidly become exhausted, while others do not yield much more than their normal current and will run for a long time.

The circuit is closed when the two poles are connected outside the fluid by a conducting path of any kind whose resistance may be very small, as in the case of a short-circuit, but is ordinarily quite considerable. It is in its passage through this external resistance that the work of the current is performed, and that the power generated in the battery is utilized. It is explained on p. 128 that this external resistance may be of two kinds—ohmic resistance akin to friction, and reducing the amount of current by converting part of the power it represents into heat; and inductive resistance, by which part of the current strength seems to disappear in consequence of a counter electromotive force induced by the current's flow. The force which causes the current of electricity to flow through the liquid and through the conducting path outside the liquid is called the *electromotive force*, or the difference in potential between the two poles.

Practical Types of Single-fluid Voltaic Cells.—The *bichromate cell* contains an electrolyte made by dissolving one pound of bichromate of potassium in ten pounds of water to which two and a half pounds of concentrated sulphuric acid have previously been slowly added. The elements are zinc and carbon, both surfaces of the zinc being utilized by placing it between two carbons. The zinc should be raised from the liquid when the battery is not in use. Such a cell has an electromotive force of about 1.95 volts, and makes an excellent cautery battery.

The *Smee cell* consists of dilute sulphuric acid as an electrolyte, with a plate of silver between two of zinc. It is an excellent cell for

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[1] *Electromotive Series.*—Zinc, cadmium, tin, lead, iron, nickel, bismuth, antimony, copper, silver, gold, platinum, and graphite.

all kinds of electrotherapeutic purposes. It has been extensively used for telegraphy where the requirements are much the same as in medical work, *i. e.*, the elements do not have to be raised from the liquid when not in use and the battery is always ready to yield a full current when the circuit is closed. To lessen polarization the surface of the silver is roughened or coated with finely divided platinum. Each cell yields about 0.65 volt.

Practical Types of Double-fluid Voltaic Cells.—The *Bunsen cell* consists of a carbon rod, the positive pole, in strong nitric acid inside a porous cell; and a hollow cylinder of zinc, the negative pole, in dilute sulphuric acid in the large outer glass cell. The voltage of each cell is about 1.95.

The *Grove cell* is similar to the Bunsen, but in it platinum is used instead of carbon.

The *Daniell cell* is a standard one. A copper electrode is in a porous cell filled with a saturated solution of sulphate of copper, and forms the positive pole. It is in the form of a hollow copper cylinder with a copper cullender at the top full of crystals of sulphate of copper. The zinc forming the negative pole is in the form of a hollow cylinder surrounding the porous cell, and is immersed in dilute sulphuric acid contained in the outer glass jar. The voltage of a Daniell cell is about 1.072. When the battery is in operation, metallic copper is deposited on the copper electrode instead of hydrogen gas, and this aids rather than interferes with the current.

The *gravity cell* uses two fluids, but depends upon their difference in specific gravity to keep them separate. The copper element is at the bottom, surrounded by crystals of sulphate of copper, and the zinc element is at the top, surrounded by a solution of sulphate of zinc, which is much lighter than a saturated solution of sulphate of copper. When in operation, the zinc is acted upon and removes acid radicles from the solution of sulphate of zinc; at the junction between the two solutions the deficiency in acid radicles in the zinc sulphate solution is made up by the abstraction of acid radicles from the copper sulphate solution, and at the surface of the copper electrode the deficiency in acid radicles results in a deposit of metallic copper. This battery is especially useful when a continuous current is required for long periods of time. It is only necessary to drop in crystals of sulphate of copper until the zinc is entirely consumed, when, of course, that also must be renewed. The two fluids will mix by diffusion if the battery is not used for some time, and in that case it may be started by pouring in a little dilute sulphuric acid or zinc sulphate solution. When the battery is first started, it is only necessary to place the zinc and copper elements in position, fill the jar with water, and throw in a handful of crystals of sulphate of copper. If placed on short-circuit, the current will soon start, and the action of the acid radicles upon the zinc element will soon result in the formation of an upper layer of zinc sulphate solution.

Double-fluid Cells with a Solid Depolarizer.—The *LeClanché cell* uses a solid depolarizer consisting of a mass of carbon and oxide of manganese tightly packed around a copper or carbon plate inside a porous cell which is sealed by a layer of pitch poured over the top. The other element is a small zinc rod in the outer glass jar, one-third full of a strong solution of sal ammoniac, chlorid of ammonium. This is a favorite type of cell for electric bells, because it requires very little care, and although it polarizes quickly, it soon becomes depolarized again by the combination of the active oxygen in the binoxid of manganese with the liberated hydrogen gas. It forms a battery which is suitable for most medical purposes. It is always ready to yield a good current, but not for any great length of time. According to Houston, a LeClanché cell which has apparently become exhausted may be made to yield a good current again by washing it out with dilute muriatic acid, and then setting it up again with a fresh charge of sal ammoniac. The electromotive force of such a cell is about 1.40 volts.

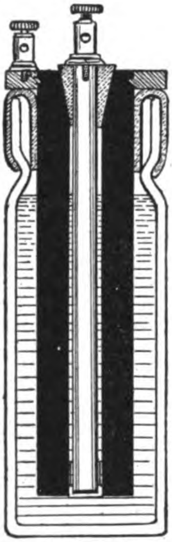

Fig. 65.—LeClanché cell.

The *Edison-Lalande cell* has zinc and copper elements with a single fluid and a solid depolarizer. The copper plate is coated with compressed oxid of copper, which absorbs the hydrogen gas liberated during the action of the cell, and is to a corresponding extent converted into metallic copper. There are two zinc plates alongside the copper plate, and the electrolyte is a solution of caustic potash or caustic soda in water. A layer of paraffin oil is poured over the top of the liquid to prevent the carbonic acid of the air from combining with the soda or potash of the electrolyte. The electromotive force of a cell of this type is 0.66 volt.

The *chlorid of silver cell* contains a zinc and silver couple in electrolytes of fused chlorid of silver and sal ammoniac. Each cell gives a voltage of about 1.03. It is a type which is very serviceable for medical purposes, and is usually set up in a series battery so arranged that from one to the entire number of cells may be used. It is a battery which produces a small current with high electromotive force. It is hardly a practicable type of battery for cautery or any other purpose requiring a heavy current. Some other type of voltaic cell is better in this way, or a storage battery of several cells in series, or, still more convenient, the electric-lighting current with a suitable transformer and rheostat.

Clark's Standard Cell.—For measuring the electromotive force of a voltaic cell a certain absolute and definite standard is necessary for purposes of comparison, and this is found in the current produced by a Clark's cell. There are some others which can be used in the same way, but it will be sufficient to describe this one in detail. It consists of a sealed glass tube with silver wires leading in at top and bottom and containing a positive mass of pure mercury covered by a paste of mercurous sulphate and zinc sulphate, and a negative mass of pure zinc. No hydrogen gas is liberated, and this is the reason that the tube may be hermetically sealed. The paste forming the electrolyte is made by boiling mercurous sulphate in a saturated solution of zinc sulphate, and should contain enough of the solution to keep it semifluid. The cell remains ready for use for a long time. Its electromotive force is 1.457 volts.

Fleming's Standard Cell.—This is another cell which gives a very definite electromotive force, and which may be used for measuring an unknown voltage. It is made of a U-shaped tube in one arm of which is the zinc electrode in a solution of sulphate of zinc, while the copper electrode is in the other arm in a solution of sulphate of copper. Its potential is 1.074 volts.

Corrections must be made for temperature with either of these standard cells. The voltage of the Fleming cell, for instance, diminishes 0.08 per cent. for every degree Centigrade of elevation in temperature.

The Cadmium Cell.—A cadmium cell is another standard cell, and has recently taken the place of a Clark cell for measuring the electromotive force of different voltaic cells. The negative electrode consists of a mass of cadmium amalgam fused on to the end of a platinum wire. It is in one vertical arm of a glass cell shaped like a letter H. The cadmium amalgam is covered with a loose mass of crystals of sulphate of cadmium, and above that is the general electrolyte. This is a solution of sulphate of cadmium, and is the same in both vertical arms and in the horizontal junction of the glass cell. The positive electrode is a plate of amalgamated platinum fused on to the end of a platinum wire, and covered by a paste of sulphate of mercury, which fills the lower part of the other vertical arm of the glass cell. From these two electrodes fine glass tubes lead through the paraffin wax and cork and sealing-wax, which hermetically seal the cell at the top of the two vertical arms. The two fine glass tubes contain metallic mercury, by means of which the conducting rods are placed in electric contact with the positive and negative electrodes respectively. The advantage of this cell over the Clark cell is that it requires practically no correction for changes in temperature.

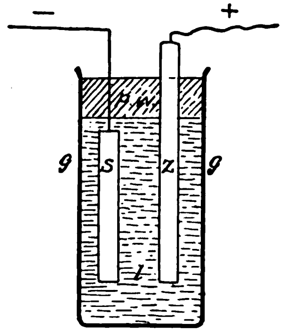

Fig. 66.—Chlorid of silver cell.

The Chlorid of Silver Cell—De La Rue's (Fig. 66).—Each cell consists of a glass vessel, *g*, *g*, about 6 inches high and 1 inch in diameter, closed by paraffin wax, *P. W.* The two electrodes are of zinc, *z*, and silver, *s*, and the latter is wrapped with paraffin paper to prevent it from coming into contact with the zinc, since the battery is especially designed to be portable. The electrolyte is one part chlorid of ammonium and forty parts water. The zinc is the element acted upon during the operation of the battery, and when the battery is not in use, the zinc becomes covered by a coating of oxychlorid of zinc, which reduces the flow of current technically by increasing the internal resistance of the cell. This does not occur if the cell is in frequent use, or if the zinc is taken out and scraped. Less of the oxychlorid of zinc is formed if the cell is hermetically sealed. In any case the full strength of the cell is elicited by a few seconds short-circuit in the case of a cell which has already been in use, or by fifteen minutes short-circuit if the cell is entirely new. The internal resistance of a cell of the size described here and with a zinc rod $\frac{3}{16}$ inch in diameter is three or four ohms. The electromotive force is about 1.03 volts. The wire connected with the zinc rod forms the negative (—) pole in the external circuit.

DETAILS OF VARIOUS VOLTAIC CELLS.

	+ Plate. =Negative Pole.	Solutions Separated by Porous Cell.		— Plate. = Positive Pole.	Volts.
Daniell.	Zinc amalg.	Sulphuric acid, 7½ to 1.	Saturated solution of copper sulphate.	Copper.	1.079
"	"	" 22 to 1.	Saturated solution of copper sulphate.	"	0.978
"	"	" 22 to 1.	Nitrate of copper (saturated).	"	1.000
"	"	" 22 to 1.	Sulphate of copper.	"	0.909
" P. O. Standard.	"	Sulphate of zinc (saturated solution).	Sulphate of copper (saturated solution).	"	1.079
Grove.	"	Sulphuric acid 7½ to 1.	Nitric acid (fuming).	Platinum.	1.956
"	"	Salt water.	Nitric acid, sp. gr., 1.33.	"	1.904
"	"	Sulphuric acid, 22 to 1.	Nitric acid, sp. gr., 1.33.	"	1.810
"	"	Sulphate of zinc.	Nitric acid, sp. gr., 1.33.	"	1.672
Bunsen.	"	Dilute sulphuric acid.	Nitric acid.	Carbon.	1.734
Smee.	Zinc.	Sulphuric acid, 1; water, 7.	. . . .	Platinized silver.	0.47
Walker.	"	Sulphuric acid, 1; water, 7.	. . . .	Platinized carbon.	0.65

Note.—These E.M.F.'s are 1.1 per cent. too high, and should be multiplied by 0.9889, the ratio of the B. A. unit to the legal ohm.

Callan.	Zinc amalg.	Dilute sulphuric acid.	Nitric acid.	Cast iron.	1.700
Poggendorf.	"	Dilute sulphuric acid.	(Dichromate of potash).	Carbon.	(1.796) (2.028)
Marie, Davy.	"	Sulphuric acid, 22 to 1.	Paste of sulphate of mercury.	"	1.524
"	"	Dilute sulphuric acid.	Paste of sulphate of mercury.	"	1.33
LeClanché.	"	Solution of sal ammoniac.	Binoxid of manganese.	"	1.48
De la Rue	Zinc.	Chlorid of ammonium.		Silver, + AgCl.	1.030
Skrivanov (pocket form).	"	Solution, 75 caustic potash to 100 water.		" "	1.4 to 1.5
Becquerel.	Zinc amalg.	Sulphate of zinc.	Sulphate of lead.	Lead.	0.55
Niaudet.	"	Common salt.	Chlorid of lime.	Carbon.	1.65
Duchemin.	"	"	Perchlorid of iron.	Lead.	1.541
"	Platinum.	Dilute sulphuric acid.	Dilute sulphuric acid.	Platinum.	1.79
Latimer Clark (standard cell).	Zinc amalg.	Sulphate of zinc.	Paste of sulphate of mercury.	Mercury.	1.457
Howell's manganese, internal res. = 1 ohm (Hockin).	Zinc amalg.	Ammonium sulphate, 25 grams crystallized to 1 litre water.	Sulphuric acid, 1 part acid to 5 parts water.	Carbon + manganese dioxid + manganese sulphate.	2.04
Higgins' cascade, internal res. = 0.170 ohm.	Zinc in mercury.	Chromic acid.	Sulphuric acid.	Carbon.	1.9
Thame's.	Zinc.	Dilute sulphuric acid.	Nitric acid, + CrO_2Cl_2.	"	2
Bennet's internal res. = 5 ohms.	"	Potassium hydroxid (KHO) with distilled water.	Dampened with (KHO) and water.	Iron can with iron borings.	1.3

	+ PLATE. =NEGATIVE POLE.	SOLUTIONS SEPARATED BY POROUS CELL.		— PLATE. = POSITIVE POLE.	VOLTS.
Lalande-Chaperon.	Zinc amalg.	Caustic soda solution.	Oxid of copper or "copper scale."	Iron.	1
Faure's secondary battery	Lead plate coated with minium.	Dilute sulphuric acid.	Dilute sulphuric acid.	Lead plate coated with minium.	2. to 2.2
Sellon-Volckmar.	Lead plate primed with minium.	Solution sulphuric acid, sp. gr., 1.100.	Solution sulphuric acid, sp. gr., 1.100.	Lead plate primed with minium.	2.15
Planté.	Lead.	Dilute sulphuric acid.	Dilute sulphuric acid.	Lead (spongy).	2 to 2.2

Note.—The + pole is *electronegative* to the other in all batteries.

Testing the Porous Cell in a Voltaic Cell.—The porous cells used in batteries may be tested in two ways: by actual use in a standard cell (British Government test), or by filling with distilled water at a temperature of 14° C., and seeing if the leakage in twenty-four hours amounts to at least 15 per cent. (French Government test).

Precautions in Mixing Battery Fluids.—When mixing battery fluids containing sulphuric acid, it is very essential to pour the acid slowly into the water. Heat is produced by mixing these two fluids, and if the whole quantity of acid is subjected at once to the action of water, the glass jar or cell will certainly crack.

Dry Cells.—The so-called "dry cells" of modern commerce differ in no essential respect from an ordinary zinc-carbon voltaic cell. The amount of fluid, however, is small, and it is held in some absorbent material like sawdust, or it may be in a jelly-like mass. The outside of such a cell is generally a zinc container which forms one electrode, while the other electrode is a rectangular carbon rod around which the electrolyte is packed. The can is sealed by a layer of asphaltum to prevent evaporation of the electrolyte.

Batteries of dry cells set up in series are very convenient for actuating a faradic coil or for the lighter forms of electrolysis and galvanism. They are not very well adapted to cautery purposes or to *x*-ray work.

Féry's recently patented dry cell is claimed to give quite a constant current. The positive pole is formed by the zinc can containing the other parts of the battery. There is a bottom layer of porous substance, such as infusorial earth, cotton, or powdered pumice-stone, moistened with such a liquid as a solution of sodium sulphate. The zinc is lined with blotting-paper or felt. The carbon positive electrode is placed in the upper part of the jar, and surrounded by a depolarizing substance, such as a mixture of graphite and mercury sulphate made into a paste with sodium sulphate solution.

Expense of Electric Power from Voltaic Cells.—The amount of zinc consumed in a voltaic battery has been calculated to be for one horse-power for each hour; $\frac{2.02}{E}$ pound of zinc, E being the electromotive force of one cell in volts. About two pounds of zinc have to be consumed per hour to obtain one horse-power from a voltaic battery. This is very much more expensive than burning coal, oil, or gas to run a dynamo and produce the same amount of electric energy when considerable power is required for any length of time. Under certain conditions, in electrotherapy, however, the voltaic battery is more economic—when only a small amount of power is required at variable periods, and only for a short time, and when a portable apparatus is required. Even under these conditions, if there is a dynamo current present for other purposes (light or power), it may often be employed with economy for medical purposes. It certainly makes it much easier to keep the apparatus in running order.

Method of Measuring the Electromotive Force of a Voltaic Cell.—This is usually accomplished by means of an apparatus called the potentiometer. This is essentially a balancing of the electromotive force to be measured by the electromotive force existing in a conductor through which a current is flowing. This means that the electromotive force in the wire through which the current is flowing is opposed to or acts in an opposite direction from the electromotive force of the cell which is being tested, and being equal to it, prevents the passage of any current either to or from that cell. The arrangement is shown in Fig. 67 (*Lehfeldt; Electrochemistry*). A uniform wire *a*—*b* is stretched tightly over a scale, usually a meter long, and is supplied with current from a uniform source, which may be one cell of a storage battery or one of the standard Clark or cadmium cells; then there will be a fall of potential of about two volts from the end *a*, which is connected to the positive electrode of the standard battery to *b*, which is connected with the negative pole. If, now, a cell to be tested, *C*, whose electromotive force is less than two volts, be connected with its positive terminal to *a*, and its negative terminal to some point, *x*, of the wire, a current will, in general, flow through it, and may be detected by the galvanometer, *G*. But if *x* be slid along the wire, a point can always be found, such that the current through *G* vanishes. This is when the potential difference from *a* to *x* is equal to the electromotive force of the cell; if contact be made to the left of this position, the galvanometer current will be in one direction; if to the right, in the opposite, hence it is easy to find the point of balance. Now substitute for *C* a standard cell, *S*, and repeat the adjustment, obtaining balance at, say, *y*. Since *i* is the current flowing through the wire, we have, by Ohm's law, that the potential difference between two points of it is equal to *i* multiplied by the resistance between those two points. Consequently—

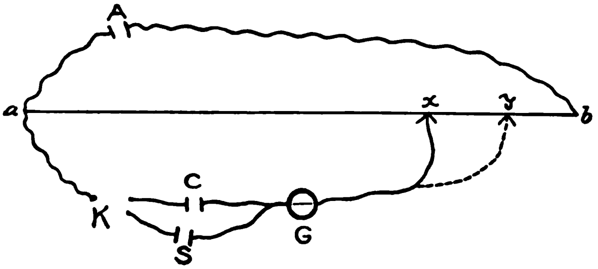

Fig. 67.—Potentiometer.

$$\text{Electromotive force of } C = i \times \text{resistance of } ax$$
$$\text{Electromotive force of } S = i \times \text{resistance of } ay$$
$$\text{and } \frac{\text{Electromotive force of } C}{\text{Electromotive force of } S} = \frac{\text{resistance } ax}{\text{resistance } ay}$$

but if the wire has a uniform resistance, the resistance is proportional to the length, hence the ratio of the two electromotive forces can be found by merely measuring the length, *ax* and *ay*. This is the simplest form of the potentiometer, and for actual use it is usually not made as a single straight wire, but as one or more coils having different resistances and with a sliding contact by which these different resistances can be placed in the circuit and accurately indicated.

For less precise measurement of the electromotive force of a voltaic cell a galvanometer with a certain resistance may be used, and this may be marked in amperes or volts. In either case the instrument may be only the size of a watch, and is invaluable for such purposes as testing the condition of a dry cell which has been kept in the shop some time before being sold, and perhaps may have been exhausted in consequence of some accidental contact.

The Internal Resistance of a Voltaic Cell.—The current from the zinc to the copper through the dilute sulphuric acid in the simple cell which we have described encounters a certain amount of resistance. This internal resistance varies with the different cells according to the component parts of the cell, the electrodes, and the electrolyte, and also with the size of the cell. · It is usually equal to two or three ohms. There are two perfectly easy ways of determining it. One way is to connect the poles of a single cell with a galvanometer and note the strength of the current; then connect two such cells in multiple, for instance, both zincs with one conducting cord, and both coppers with the other; this reduces the internal resistance one-half, and this reduction is measured by introducing a variable amount of resistance by means of a rheostat, and increasing this until the galvanometer indicates the same current strength as when only one cell was used. The increased resistance required is equal to half the internal resistance of a single cell. The formula for this calculation depends upon the equation $C=\frac{E}{R}$, indicating the law discovered by Ohm that the current is equal to the electromotive force divided by the total resistance. The current is expressed in amperes, the electromotive force in volts, and the resistance in ohms. The resistance in the case we are considering is made up of two factors—the resistance of the cell itself, R, and the resistance of the galvanometer and the rest of the external circuit, r. Using a single cell, therefore, the equation would read $C=\frac{E}{R+r}$; and if the additional resistance required to keep the same current strength in the case of two cells is L, then the equation would read $C=\frac{E}{\frac{1}{2}R+r+L}$; and since the strength of the current C is the same in both cases, $L=\frac{1}{2}R$. The other method of measuring the internal resistance of a voltaic cell is by means of the Wheatstone bridge, an account of which is given on p. 173. The knowledge of the internal resistance of a voltaic cell is of value as one of the factors in the calculation of the number and arrangement of cells for sending a certain number of amperes of current through a certain number of ohms' resistance.

The Original Voltaic Pile.—Volta, professor of natural philosophy at Pavia, in 1796, devised the electric battery, from which all those so far referred to as sources of dynamic electricity have been evolved. It consisted of a series of two different metals, piled one upon the other, and separated by cloth or paper moistened with an electrolyte. The metals were sometimes silver and zinc, and the electrolyte, water or salt and water; and in other cases zinc and copper were used with dilute acid. The current was produced by chemic action and there was no principle involved which has not already been explained in describing the modern types of voltaic battery. At the upper and lower extremities of the pile the two poles of the battery were formed by dissimilar metal disks. Each pair of dissimilar metals separated by the cloth moistened with the electrolyte formed the equivalent of one of the modern voltaic cells. In the pile the zinc element of one couple was in direct contact with the copper element of the next couple, the succession being zinc, moistened disk, copper, zinc, moistened copper, etc. It formed a series battery the voltage of which could be raised to any reasonable amount by increasing the number of disks, but the quantity of current was very small. This type of battery is not in use to-day for medical work.

Dynamic Electricity from the Contact of Dissimilar Metals.—Two dissimilar metals merely placed in contact in the air will produce an electric current, but this is most powerful when one of the metals is oxidizable and when they are dipped in a good electrolyte. According to Volta's observations, any of the metals mentioned in his contact series becomes electropositive when in contact with any one below it in the scale. Starting from the positive end of the scale there are sodium, magnesium, zinc, lead, tin, iron, copper, silver, gold, platinum, and graphite. The voltage obtained by Volta by the contact of zinc and lead was 0.210; tin and iron, 0.313; even cork in contact with platinum produces an electromotive force of 0.113 volt. Two different metals in contact in the air generate electric currents whose voltage is given in the following:

Contact Series of Metals in Air.—Each metal is + in contact with all following: Sodium, magnesium, zinc, lead, tin, iron, copper, silver, gold, platinum, graphite. Contact E.M.F. in volts: For zinc-lead, 0.210; lead-tin, 0.069; tin-iron, 0.313; iron-copper, 0.146; copper-platinum, 0.238; platinum-carbon, 0.113 (Ayrton and Perry).

Heating of Voltaic Cells.—The amount of heat generated in a voltaic cell depends upon the chemic constitution of the cell, not simply upon the current strength. This is shown in the cases of the cadmium cell and the Clark cell. Both are standard cells. They generate a perfectly definite electromotive force, which is used in measuring electromotive forces and resistances. The cadmium cell generates thirty times less heat than the Clark cell, and undergoes comparatively little change in electromotive force while in operation. This constitutes a great advantage over the Clark cell, in using which the temperature changes must be measured and their effect upon the electromotive force calculated.

THERMO-ELECTRICITY

A difference in potential is generated when the junction between two different metals is heated or cooled, and this will produce an electric current if the two other extremities of the metals are connected by a wire. This property may be used to generate electricity for medical purposes, and a large number of such couples will give a current of high potential or of great quantity, according to whether they are arranged in series or in parallel. As long as a difference in temperature is maintained, so that the junction of the metals is either hotter or cooler than the distal parts of the metals, a current will flow. Corroborating the theory of the conservation of energy, a certain amount of energy in the form of heat must be applied, and disappears as heat, to reappear as electricity.

A **thermo-electric pile** or battery is not convenient for therapeutic purposes, but it may be used as a very delicate thermometer.

A wire of one metal is bent into an inverted U-shape, as in Fig. 68, and others of another metal are soldered to its two extremities. Placing one of these junctions in a disk of melting ice whose temperature is, of course, known to be exactly 32° F., and the other in a solution whose temperature is to be tested, a current of electricity will flow through a galvanometer connected with the free extremities of the outside wires if there is any difference in temperature between the two solutions. The galvanometer deviations corresponding to different temperatures must be determined by the manufacturer of the apparatus and marked upon a scale. This furnishes very delicate measurements of the temperature of any part of the human or animal body, to which one point is applied while the other point is dipped in melting ice. The exact temperature of any part of the body may be determined in this way.

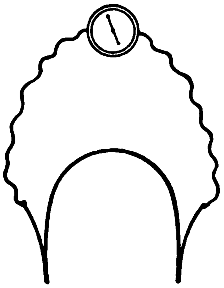

Fig. 68.—The thermo-electric thermometer.

Thermo-electric Scale.—In connection with lead, at a mean temperature of 20° C. (Matthiessen), the E.M.F.'s are in microvolts per degree centigrade:

Bismuth, commercial, in wire	+97.000
“ pure, in wire	+89.000
“ crystallized, along axis	+65.000
“ “ normal to axis	+45.000
Cobalt	+22.000
German silver	+11.750
Mercury	+0.418
Lead	0.000
Tin	−0.100
Copper of commerce	−0.100
Platinum	−0.900
Gold	−1.200
Antimony, pure, in wire	−3.800
Silver, “ “	−3.000
Zinc, “ “	−3.700
Copper, galvanoplastic	−3.800
Antimony of commerce in wire	−6.000
Arsenic	−13.560
Iron, piano wire	−17.500
Antimony, crystallized, along axis	−22.600
“ “ normal to axis	−26.400
Phosphorus (red)	−29.700
Tellurium	−502.000
Selenium	−807.000

STORAGE BATTERIES OR ACCUMULATORS

These are cells which, after being charged by the electrolytic action of a current passed through them, act exactly as do the ordinary voltaic cells. They are of service where there is a dynamo or similar source of electric current, which is either not available at all hours, or which is liable to derangement, and also when a portable outfit is required. The general principle upon which all storage batteries work is illustrated in the case of one of the older types made by the Thompson-Houston Company. It contained a copper electrode at the bottom, in a solution of sulphate of zinc, with a zinc electrode near the top. A current of electricity from a dynamo or from a primary battery was passed through this cell from the copper to the zinc. This decomposed the solution, depositing metallic zinc upon the zinc plate, and by dissolving away the copper from the other electrode, produced a concentrated solution of sulphate of copper at the bottom of the cell. The result was the formation of a regular Daniell cell of the gravity type, with the zinc electrode at the top, the copper at the bottom, and the two electrolytes, sulphate of zinc solution at the top, and sulphate of copper solution at the bottom, kept separate by their difference in specific gravity. This battery was then ready to give a current when the external circuit was made between the two poles. The direction of the current of discharge was the reverse of that of the charging current, so that the copper became the positive pole, just as in an ordinary gravity battery. The current-yield would continue, while the external curcuit was closed, until the solution of sulphate of copper had again entirely changed to a solution of zinc sulphate. The battery could be recharged by passing an electric current through it in the same way as at first. And this alternate charging and discharging can be repeated a large number of times, though eventually the electrodes are worn out and the electrolyte also needs renewal. While charging such a storage-cell, metallic zinc is deposited in a loose form, and a diaphragm is needed to keep it from falling to the bottom of the solution.

The Planté Storage Battery.—The Planté cell is the original upon which the other modern storage batteries are modeled. In it two thin sheets of lead separated by a fraction of an inch are coiled together, securing a very large extent of surface and a small distance at all points between the adjacent surfaces of the two plates. They are set in a jar of dilute sulphuric acid, and a conducting cord is attached to each plate. In this condition no current is produced on closing the circuit, because both plates have exactly the same affinity for the electrolyte and no difference in potential exists. The battery is charged by passing a current of electricity through it. Electrolysis or electrochemic decomposition takes place, by which the lead plate connected with the negative source of electricity becomes coated with finely divided metallic lead, derived from the action of the acid upon the other plate. And the surface of that one becomes converted into red lead or peroxid of lead. At one pole, then, with the storage-cell fully charged, we have metallic lead, Pb, and at the other, PbO_2. Removing the battery from the charging current, it is ready to act like an ordinary voltaic battery, and yields a current when its two poles are connected through an external circuit. The pole on which the PbO_2 (red lead or peroxid of lead) has been deposited becomes the positive pole of the battery, and the current in the external circuit flows from this to the other pole.

In the liquid electrolyte of the battery, of course, the current is continued from the Pb to the PbO_2. The reaction occurring as the total result of the discharge of a storage battery is $Pb + PbO_2 + 2H_2SO_4 = 2PbSO_4 + 2H_2O$, and during the process of charging or recharging the same equation holds good, but would be reversed: $2PbSO_4 + 2H_2O = Pb + PbO_2 + 2H_2SO_4$.

In other words, during the discharge, the metallic lead on one plate and the peroxid of lead on the other both yield to the influence of the sulphuric acid and are converted into sulphate. The dilute sulphuric acid becomes weakened, and solid sulphate of lead is produced. It is never desirable to allow a storage battery to become completely discharged, all the peroxid of lead disappearing, both plates becoming converted into PbO, or litharge, and the electromotive force falling to zero. In this condition it receives a charge much less readily and effectually than if one plate still had a considerable coating of peroxid of lead. For the same reason, when first making a storage battery, it is preferable to apply a thick coat of peroxid of lead (red lead) to one or both of the lead plates, the battery then "forming" much more quickly.

More closely analyzed, the reaction in a storage battery during its discharge consists partly in the formation of about equal quantities of solid lead sulphate at each pole, and a reduction of the strength of the acid occurs at both poles, but is more marked at the positive pole. One result of the discharge is seen at the anode, where the lead combines with a sulphion to form sulphate of lead, and transfers a negative charge of electricity to the liquid in the direction of the cathode. The equation $Pb + SO_4 = PbSO_4 + 2-$ expresses the reaction occurring at the positive pole. The reaction at the cathode is expressed by the equation $PbO_2 + H_2SO_4 + 2H.\ 2- = PbSO_4 + 2H_2O$, which indicates that peroxid of lead, with sulphuric acid and hydrogen and a negative charge, result in the formation of sulphate of lead and water.

When the storage battery is being charged, the same equations also hold good, but are simply reversed.

With the strength of acid ordinarily used, a storage-cell cools slightly while yielding a current. The full explanation of why this should be the case instead of the fluid becoming warm, as with the Daniell cell, is beyond the scope of the present book. But two factors are that the final results of the chemic change are much weakened acid and solid lead sulphate, and that the internal resistance of a storage-cell is very much smaller than that of an ordinary voltaic cell. When a storage battery is being recharged, the electrolyte acquires its condition of being quite a strong solution of sulphuric acid, and the process should be continued until gases are freely given off from the electrolyte, which becomes slightly warm during the process. These gases are hydrogen and oxygen, and the presence of a spark or flame would cause an explosion. The large bubbles are hydrogen, the small ones, oxygen. The sulphuric acid employed usually has a density of 1.18 or 1.20, and is much stronger than "dilute sulphuric acid." As the water evaporates, distilled water is the best to add, because it brings about no change in the composition of the electrolyte, while ordinary water contains an amount of chlorids sufficient, after several additions, to impair the efficiency of the cell.

The **modern storage battery** is made up of grids, which are molded forms of lead producing hardly more than a framework until they are "pasted." The grid which is to form the positive pole of the storage battery is "pasted," or thoroughly filled under hydraulic pressure, with a paste of red lead and some substance which will be dissolved out by the weak sulphuric acid, and leave a porous mass presenting a relatively very large surface of peroxid of lead exposed to chemic action. The other grid is pasted in the same way with spongy lead. The active surfaces presented are about 200 or 400 square inches per pound. This method of construction also prevents the separation of the active layer. The surfaces of the positive and negative grids are placed very close together, being kept from actual contact by a corrugated sheet of hard rubber with numerous perforations, and also by a thin piece of bass wood. The latter, under the action of the acid, becomes 30 per cent. porous, but still has such fine pores that it effectually prevents the formation of a lead tree. The latter is a sort of crystalline mass of lead, looking like the familiar Christmas tree, which would have a tendency to form between two lead plates in a storage battery and very greatly impair the efficiency of the battery. A storage battery is usually made up with three positive and two negative grids in each cell. This does not increase the voltage of the cell over what would be the case with only one plate of each kind. It does, however, increase the amperage and does so in a manner more economical in regard to size and weight than would be the case with a single pair of correspondingly larger plates. Five such cells would have a potential of about 10 volts, and would give a current of about 10 amperes, through a resistance of 1 ohm, for about ten hours continuously, or as the total of several shorter periods. A battery of this capacity weighs from 100 to 200 pounds.

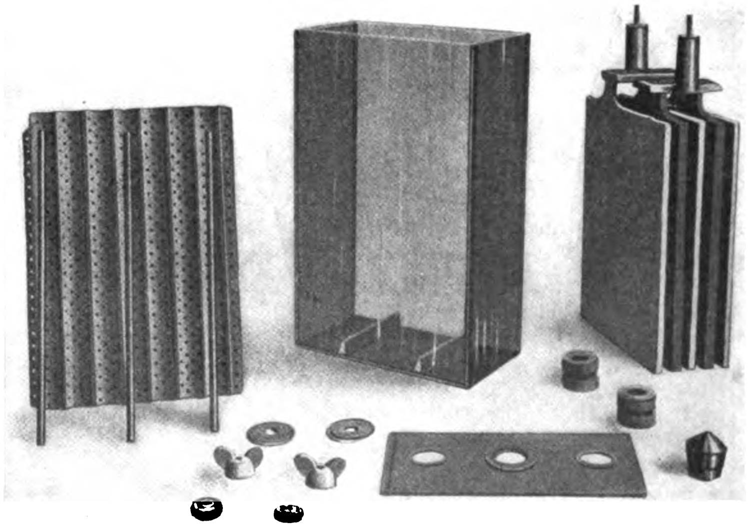

Fig. 69.—Storage cell in parts. (National Battery Co.)

The chlorid type of storage battery, made by the Electric Storage Battery Company, employs antimony grids, with buttons of peroxid of lead on the negative and of metallic lead on the positive plate. Each cell contains several positive and several negative plates, and a cell 16 inches high and weighing, when filled with 40 pounds of weak acid, 136 pounds, will give 25 amperes for eight hours or 35 amperes for four hours, or 50 amperes for three hours, or 100 amperes for one hour. Its potential is only 2 volts, and to obtain the heavier currents it is necessary to have several such cells connected up in series.

The **Edison storage battery** has positive and negative plates of thin nickel steel, with perforations in which the active material is consolidated under hydraulic pressure. The surface of the positive plate is made up of powdered peroxid of nickel mixed with powdered graphite; the negative plate contains powdered oxid of iron and graphite. The electrolyte is an aqueous solution of caustic potash. Passing a current through the cell in order to charge it converts the positive plate into hyperoxid of nickel and the negative plate into spongy metallic iron. After discharge the grids are covered with peroxid of nickel and oxid of iron. There are a number of plates in each cell; its voltage is 1.5, and it is a much lighter cell than the lead storage-cell.

Faure's Accumulator.—A single cell consists of two lead plates coated with a paste of minium (Pb_3O_4), with dilute sulphuric acid (H_2SO_4). The coated plates are covered with felt or cloth, to prevent contact with each other, and are rolled up together and immersed in dilute sulphuric acid. The following reaction takes place in both plates before the application of any current. The sulphuric acid acts upon the minium: $Pb_3O_4 + 2H_2SO_4 = PbO_2 + PbSO_4 + 2H_2O$. If a charging current from a battery or dynamo is now applied, there is the following result at the plate connected with the positive wire from the dynamo: $PbSO_4 + H_2O + O = PbO_2 + H_2SO_4$. In other words, the electrolytic liberation of oxygen at the positive electrode results in a complex reaction, producing an additional deposit of PbO_2 and an increased amount of H_2SO_4. At the plate connected with the negative wire from the dynamo a contrary effect is produced. It is one of deoxidation, and the PbO_2 and $PbSO_4$ are both reduced to spongy metallic lead; the other products there being H_2SO_4 and H_2O. After being completely charged, the storage-cell is capable of giving a current of electricity if the two plates are connected by means of an external circuit. The current will be in the opposite direction to the charging current, and has an electromotive force of about 2 volts. The reaction at each plate during discharge just reverses that occurring while the battery is being charged.

The **care of a storage battery** consists chiefly in charging and recharging it, seeing that it does not become short-circuited, and that the fluid is maintained at the original quantity and strength.

Charging a Storage Battery.—Fig. 70, *A*, shows the connections to be made when the storage battery is charged from the 110 volts direct incandescent light circuit. From the positive wire the current is led across a fused knife switch to a bank of four 16 c. p. incandescent lamps, arranged in parallel, and acting as a resistance, so that only the desired current strength of three amperes or so can pass through the storage battery. From the bank of incandescent lamps the positive current is led to the positive pole of the storage battery (connecting the positive electric-light wire with the wrong pole of the storage battery would produce damage), and thence across a fused knife switch to the negative electric-light wire. It takes about ten hours to charge a storage battery.

Fig. 70, *B*, shows the arrangement for charging a storage battery from the 550 volts direct current of the trolley-car system. The difference to be noted is that the bank of incandescent lamps consists of five parallel series of five 16 c. p. incandescent lamps each. This results in the same current strength reaching the positive pole of the storage battery, as in the case of the 110 volts direct current controlled by the single lamps in parallel.

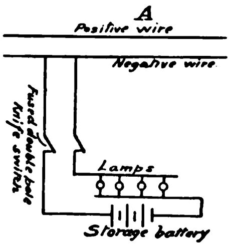

Fig. 70, *A*.—For 110 volts direct current.

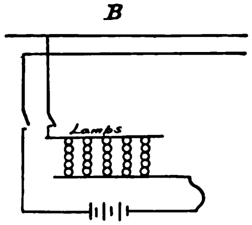

Fig. 70, *B*.—For 550 volts direct current from the trolley system.

Where the current is supplied by an alternating incandescent light circuit of 110 or 125 volts, it is necessary to have the current changed so as to be unidirectional. This is accomplished by introducing a mercury arc rectifier into the circuit between one incandescent light wire and the storage battery, with its bank of lamps to regulate the strength of the current.

The *mercury arc rectifier* consists of a vacuum tube with a reservoir of mercury at the bottom which forms the cathode, with which one wire connects and there are two other leading-in wires terminating in iron anodes. The cathode in a vacuum tube has a reluctance which must be overcome by the disintegration of its surface. And if such a tube is simply interposed between the positive pole of the storage battery and one incandescent light wire, while the other pole of the storage battery is connected with the other incandescent light wire, no current will pass. The terminals *A* and *a* in the mercury vapor vacuum tube (Fig. 71) will remain as completely insulated as if they

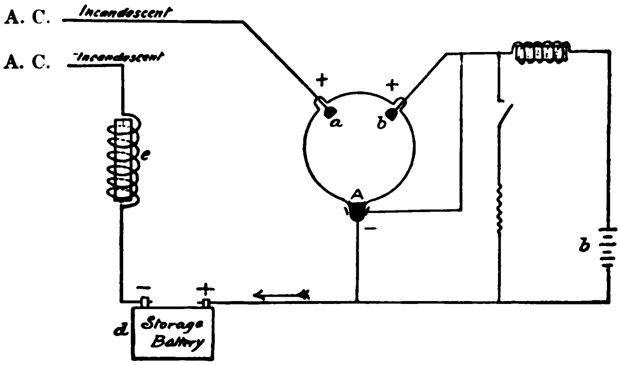

Fig. 71.—Mercury arc rectifier (Cooper Hewitt tube).

were separated by an inch or two in the open air. The surface of *A* may, however, be disintegrated and *A* be made to act as a cathode and permit the flow of currents in the direction from *a* to *A*. And this can be done without disintegrating the surface of *a*, which remains incapable of acting as a cathode, and the tube will not transmit currents in the direction from *A* to *a*. There are thus transmitted through the storage battery a succession of currents in only one direction and care is taken to have the connection made with the proper poles of the storage battery. This succession of currents may be made an almost continuous current by introducing a self-induction coil at E. Each time the current ceases to flow, an extra current in the same direction is produced by inductance. The other side of the diagram shows the arrangement for disintegrating the surface of the mercury cathode *A*, and keeping it so, and constantly in condition to act as a cathode. This is accomplished by first sending an induction spark from the other anode *b* to *A*, and following this up with a constant current of 3½ amperes and 14 volts between the same points. A storage battery *b* supplies this current, and produces the initial or primary discharge by means of a self-induction coil and a quick break switch.

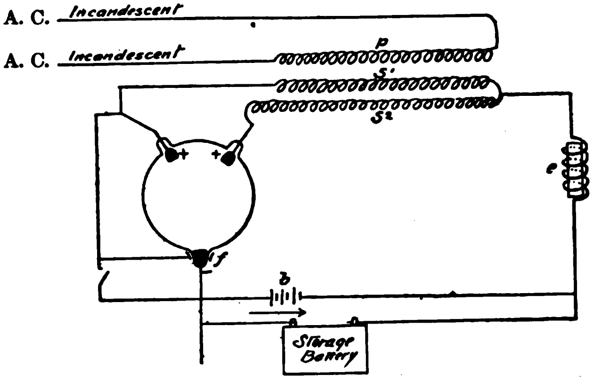

Fig. 72.—Mercury vapor vacuum tube as a double current rectifier.

In the arrangement thus far described there is a direct connection between the dynamo circuit and the storage battery which is being charged; but only half of the currents from the dynamo are utilized in any way.

Fig. 72 shows an arrangement by which both sets of currents are utilized indirectly by means of secondary induction coils. The vacuum tube must be primed, or the current started through it by a spark from a storage battery and a self-induction coil. After that an induced current is sent through the vacuum tube from two secondary coils alternately. These two coils have the same number of similar turns, but in the opposite direction. Currents are excited in one of these by the alternating current in the primary coil. One of the secondary coils is connected with one anode of the vacuum tube, on the one hand, and with a self-induction coil and a storage battery and the mercury cathode, on the other hand. The other secondary coil forms part of a similar complete circuit starting from the other anode of the vacuum tube.

The surface of the mercury is disintegrated by a spark from the priming battery, and thereafter no battery current is necessary, only the secondary currents; and their potential is kept from falling to zero by the presence of the self-induction coils. Each secondary coil sends impulses in both directions, but only those in the direction from the anode to the cathode can pass through the mercury vapor tube. There are currents in this direction practically all the time; when one coil is not sending one, the other is.

A similar arrangement is used to rectify *triphase currents,* the transformer having three secondary coils. And Mr. Cooper Hewitt reports that he has succeeded in making a rectifier supplying a direct continuous current of 30 amperes and 500 volts with an efficiency of 98 per cent.

A *mechanic rectifier for alternating currents* for use in charging storage batteries may consist of a step-down transformer to reduce the voltage to the figure required, and an electric vibrator on the same principle as an electric bell. This is regulated so that the contact is made only at the times when the current is flowing in the same direction. Such an apparatus devised by Soulier[1] is said to run perfectly steadily for a long time, and not to become hot like electrolytic rectifiers. It has no liquid to be renewed, and consumes less current.

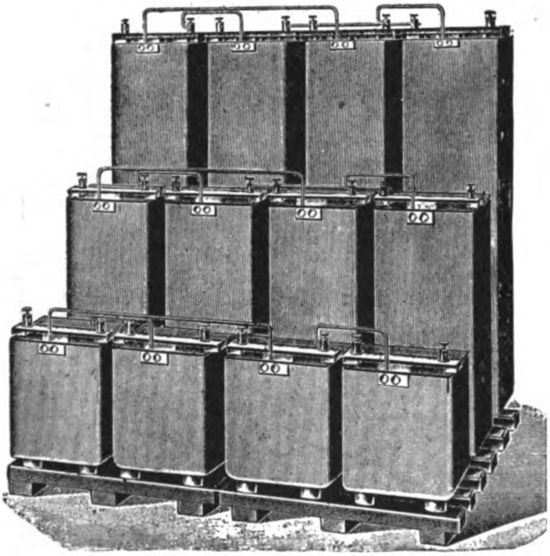

Fig. 73.—Electrolytic rectifier.

Electrolytic rectifiers are on the same principle as the aluminum cell used to rectify an alternating current for *x*-ray work. They are the simplest and cheapest thing for transforming either an alternating or a triphase current into a direct current for charging a storage battery. The rectifier consists of four of the "aluminum cells" shown in Fig. 73, where three sets of different sizes are shown. A set of four of the size corresponding with the size of the storage battery to be charged are con-

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[1] Exposition de Physique, April, 1906.

nected, as shown in Fig. 74. One alternating current wire is connected with the lead of one cell and with the aluminum of another. The other wire of the alternating circuit is connected with the lead of the third and with the aluminum of the fourth cell. The wire which is to deliver the positive current to the storage battery is connected with the aluminum of the two cells, whose lead is connected with the two alternating current wires. The negative wire comes from the lead of the two cells whose aluminum is connected with the alternating current wires. In regard to any one cell polarization prevents the flow of the current in one direction, while offering very little obstruction in the other. At each alternation in the primary current cells 1 and 3 take turns in allowing a current to pass in the direction indicated, and so do cells 2 and 4. The fluid used is a strong solution of Rochelle salt.

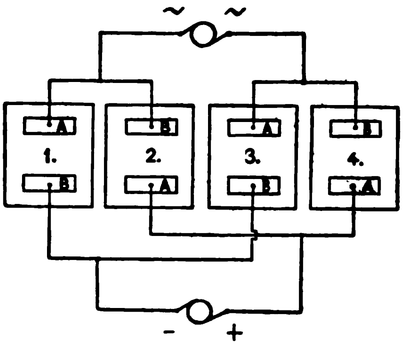

Fig. 74.—Scheme of connection of electrolytic rectifier for the transformation of alternating into continuous current.

A Booster.—In the power-houses of the trolley-car system the storage batteries are of tremendous power and are formed by a series of hundreds of large cells and require a greater voltage than that of the line wire to charge them. So that instead of having to use a reduced voltage, as in small establishments, it is necessary to supply a current of increased voltage. This is done by a special rotary converter or motor generator, which is called a booster. This word *boost* is a colloquial expression for help up or push up.

Storage-cells may be used in parallel ("multiple") or in series or a combination of the two, just like ordinary voltaic cells. Their large capacity and the ability to recharge them constitute very great advantages for many kinds of therapeutic work.

They are especially necessary when a portable outfit of great power is required as for *x*-ray work where a dynamo current is not to be obtained; also for use where the electric-light current is only turned on after dark and when it is liable to frequent derangement.

THE PRODUCTION OF ELECTRICITY BY ELECTROMAGNETIC INDUCTION

For almost every purpose requiring a large amount of electric current this is obtained most economically and conveniently from dynamos and similar generators. These all depend upon the principle that the motion of a magnet or of a coil of wire through which a current of electricity is passing will induce an electric current in a neighboring coil of wire. It was natural to expect that currents of electricity in one wire would produce currents of the same general sort in another wire, but it was a discovery of the greatest importance when Michael Faraday, in 1831, found that the motion of magnets would generate electric currents in neighboring wires. This had been preceded and was led up to by Oersted's discovery that a current of electricity in a wire will induce magnetism in a neighboring iron or steel rod.

The relation between electricity and magnetism is most intimate, and it requires only the proper apparatus to convert force manifested as electricity into force manifested as magnetism, or vice versâ. There are several important properties which illustrate this relation, and which are used in the construction of apparatus for the production, measurement, or regulation of electricity for medical purposes.

Directive Effect of Dynamic Electricity upon a Magnetic Needle.—A current of electricity passing through a wire causes a magnetic needle, like a compass needle, to tend to assume a position at a right angle to the direction of the current. If the wire is above the needle and the current is passing from south to north, the needle will turn with its north pole to the west. When the current passes below the needle, but from north to south, the needle will again deviate to the west. A current passing through a loop of wire from south to north above the needle and returning from north to south below the needle will produce a correspondingly strong deviation toward the west. If the direction of the current is reversed, the needle will deviate to the east. The effect of a current passing through a coil of wire is still greater, and in one type of galvanometer the deviation of a needle produced by a current passing through such a coil is used as a means of measuring even the weakest as well as the strongest currents. The amount of deviation is dependent upon the quantity of the current or its amperage, not on its pressure or voltage, and the current from the smallest kind of a voltaic cell may produce a greater deviation than the discharge from the most powerful static machine.

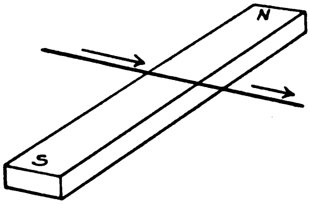

Fig. 75.—Magnetism induced by an electric current passing through a straight wire.

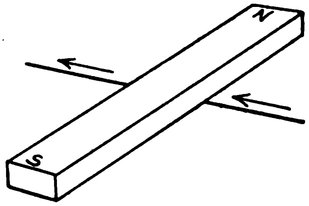

Fig. 76.—Position of the induced magnetic poles when a straight wire passes under the iron bar.

Magnetizing Effect of Dynamic Electricity upon Iron and Steel.—A bar of steel surrounded by a coil of wire through which a current of electricity passes becomes a magnet, and the question as to which end of the steel becomes the north pole depends upon the direction in which the current passes, from right to left, or vice versâ.

Fig. 75 represents the case of a straight wire crossing above a steel bar, and the current passing in the direction indicated by the arrows. The steel bar becomes a magnet with its north pole at the end indicated by N, and its south pole at S. In this diagram more clearly than in any other case is shown the truth of one rule for determining which pole of an electromagnet is the north and which the south. The rule is that a person swimming with the current of electricity at any part of the wire and facing the electromagnet will have the north pole at his left hand. If the arrows indicating the direction were reversed, the poles of the electromagnet would also be reversed.

Fig. 76 shows the position of the magnetic poles when a straight wire crosses beneath the steel rod and the current flows in the direction shown by the arrows.

Fig. 77 shows the position of the induced magnetic poles when the wire forms a single loop passing around the steel bar in a plane at about a right angle to its long axis. In such a case the rule most readily applied is that if one end of the coil be toward the observer and the current is passing in the direction of the hands of a watch, then it is the south magnetic pole which is induced at that end.

Fig. 78 shows the case of a current passing through a coil or helix, this particular one being a right-handed or dextrorsal helix. The current in the diagram is represented first and most important as passing in the direction of the hands of a watch and also secondly as progressing from the end near the observer to the other end. The first fact determines the position of the induced magnetic poles, the south pole being at the end near the observer.

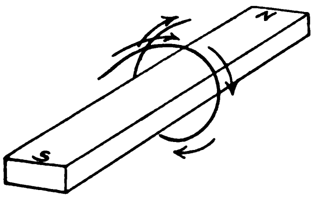

Fig. 77.—Position of magnetic poles induced by current through a loop of wire.

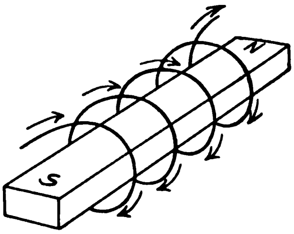

Fig. 78.—Position of magnetic poles induced by current through a dextrorsal helix.

Fig. 79 shows the case of a left-handed helix in which the current, as seen from the left end of the helix, passes in a direction contrary to that of the hands of a watch, and consequently it is the north magnetic pole which is induced at that end. In this case the end of the wire marked 1 may be connected with the positive pole of a voltaic battery, and the end marked 2 with the negative pole of the battery. The current passes in a curve from 1 to 2. The observer may go to the other end of the helix and apply the same rule for the determination of the polarity. As seen from that end, the current passes in the direction of the hands of a watch, and consequently the south pole is at that end.

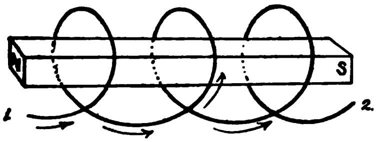

Fig. 79.—Position of poles induced by sinistrorsal helix when the current passes away from the observer.

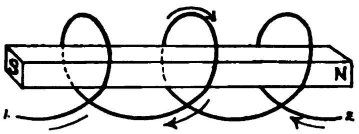

Fig. 80.—Position of magnetic poles induced by sinistrorsal helix when current passes toward observer.

Fig. 80 shows the current passing through a left-handed helix, but in a direction from 2 to 1, just the opposite of that of the current in the preceding diagram. Applying the same rule, we find that an observer at the end marked 1 would see the current passing in the direction of the hands of a watch and that consequently the south pole would be at the end nearest him, *i. e.*, at 1 instead of at 2, as in the previous example.

Fig. 81 shows the idea of a right-handed spiral, and if the current flows in the direction indicated by the arrow, *i. e.*, in the direction of the hands of a watch, the pole toward the observer is the south pole. If the current were flowing in the opposite direction, through the same dextrorsal or right-handed spiral the polarity of the electromagnet would be reversed.

Fig. 82 shows the idea of a left-handed spiral, and if the current flows contrary to the hands of a watch, as indicated by the arrow, the north pole is the one nearest the observer. If the current flowed in the opposite direction, the magnetic polarity would be reversed.

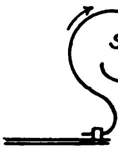

Fig. 81.—Magnetic polarity induced by current in the direction of a right-hand spiral.

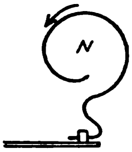

Fig. 82.—Magnetic polarity induced by current in the direction of a left-hand spiral.

Fig. 83 represents the case of a right-handed helix in which the wire progresses in a curve from one end to the other, and then back to the first end, still continuing to pass around the axis in the same right-handed direction throughout. This is the way in which thread is generally wound upon a spool. Both layers act in the same way to induce a south magnetic pole at the end where the current is seen by the observer to pass in the direction of the hands of a watch. In the same diagram, if the arrows indicating the direction of the electric current were reversed, the polarity of the magnet would also be reversed. The diagram as shown in the engraving illustrates the case of the usual electromagnet except that in actual practice it is not necessary to have the turns widely separated. They are really wound as closely as thread upon a spool, the current being confined and made to pass through the many turns of wire by the insulation of the latter. If a bare wire were closely wound in this way, the current would pass from one end of the coil to the other over the shortest path provided by the contact of different turns with each other. Very little current would pass through

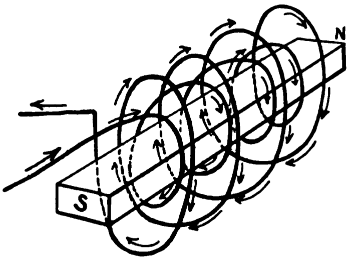

Fig. 83.—Magnetic polarity induced by several layers of wire wound back and forth upon a spool.

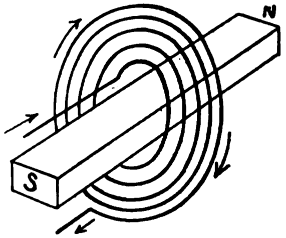

Fig. 84.—Magnetic polarity induced by a current through a flat spiral.

the whole length of the wire, and the resulting magnetization would be very weak.

Fig. 84 shows the case of a flat spiral surrounding a steel bar which is at a right angle to the plane of the spiral. Here again the direction of the current with the hands of a watch at the end near the observer, shows that this is the south pole of the induced magnet. The spiral in the diagram is a right-handed one, but here, as in all other cases, the polarity of the induced magnetism is not controlled by the direction in which the wire is wound, but by the direction in which the current passes through the wire. Tracing the wire from its connection with the positive pole of the battery and finding the direction in which it passes around the coil enables one to determine the polarity of the induced magnet, and this can be reversed by simply changing the connection of the wires with the two poles of the battery. This flat spiral winding of the wire is adopted in certain induction coils, especially the powerful ones used for *x*-ray purposes. The amount of induction is practically the same as with the same number of turns in the form of a helix.

The following diagrams from Houston (Fig. 85) give an exceedingly easy way to determine the polarity of an electromagnet when the direction of the current is known. At the north pole of the induced magnet the arrows on the letter N indicate the direction of the current, and similarly with the letter S at the south end.

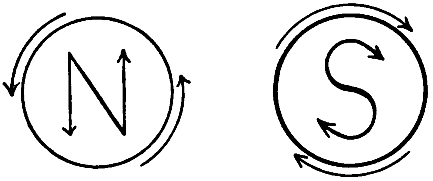

Fig. 85.—Mnemonic diagram of direction of currents inducing north and south magnetic polarity.

A steel bar which has been magnetized by an electric current retains its magnetism and is a permanent magnet.

A soft-iron (wrought iron or malleable iron) rod becomes an equally strong magnet almost the instant the current is turned on, but loses its magnetism almost the instant the current is turned off. In many forms of apparatus for use in medicine this alternation from a condition of powerful magnetism to practically complete absence of magnetism takes place thousands of times a minute.

Magnetization During the Flow of the Current.—From the time the current is turned on until it is turned off the soft-iron rod remains an equally strong magnet and with its polarity unchanged. This is the case when the electric current is uniform as to direction and strength. Any variation in either the polarity or strength of the electric current will produce a corresponding change in the polarity or strength of the magnet. It is important to remember that the effect of an electric current upon an iron core is continuous as long as the current lasts. This is not the case with two other forms of induction, which we shall have to consider. A current of electricity induced in a coil by a magnet is only momentary, and occurs only when the magnet is carried toward or away from the coil. The electric current does not continue to flow while the magnet is at rest within the coil or anywhere else. The other case is that of electric currents induced in other wires by a current passing through a primary wire. The currents are induced only when the primary current is made or broken, or when its strength is increased or diminished, or when it is brought near to or away from the secondary wire, and in either case it is of momentary duration. No electric induction takes place during the uniform flow of an electric current, but that same uniform flow will maintain magnetic induction in an iron core.

Magnetic Properties of Voltaic Currents.—Iron filings are attracted by every part of a wire through which an electric current is flowing, and if the wire is passed vertically through a hole in a piece of paper on which iron filings have been sprinkled, the latter will arrange themselves in concentric rings corresponding to the lines of force familiar to us in the case of the ordinary magnet. The lines of force in the case of a wire through which an electric current is passing are in planes at right angles to the length of the wire, and pass around the wire in concentric circles. The force has a direction which depends upon the direction of the current in the wire.

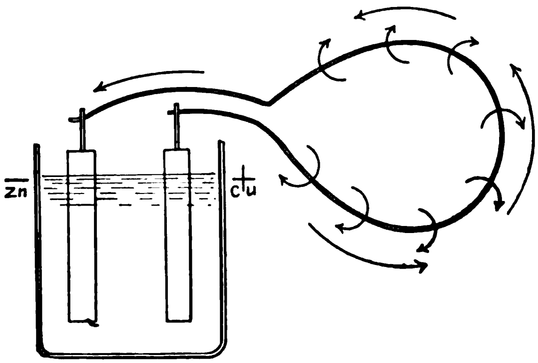

Fig. 86.—Direction of the lines of force or magnetic whorls about a current of electricity.

Fig. 86 illustrates the direction of the *lines of force* or *magnetic whorls* about a current of electricity. The direction of the lines in relation to the flow of the electric current may be likened to the right-handed direction in which a cork-screw has to be turned as it pushes forward into the cork. Ampere constructed a solenoid (Fig. 86) or helix of wire, freely suspended in a horizontal position, and found that when a current of electricity passed through it, the solenoid possessed every property of a magnet. It assumed a north and south direction, and exerted an attraction for iron or steel. And if such a coil is near a magnet, the coil will swing into position in relation with the magnet exactly as if it were a compass needle. The d'Arsonval amperemeter or milliamperemeter, a type of galvanometer which is extremely useful in electrotherapeutics, depends upon this principle; the stronger the electric current which passes through the coil, the stronger its magnetism, and the greater its deviation under the influence of a stationary permanent magnet.

A single loop of wire (Fig. 86) through which an electric current is passing has the properties of a magnet whose north pole is situated at the face at which the flux leaves the loop. The small arrows in the illustration represent the magnetic whorls or flux surrounding the wire through which the current is passing in the direction indicated by the large arrows, so that the surface of the loop toward the observer in the diagram has north polarity.

The Power of Electromagnets.—This, in electric parlance, varies with the number of ampere turns. In other words, the greater the number of turns of wire through which a current of a certain number of amperes is passing, or the greater the number of amperes passing through a wire with the same number of turns, the stronger is the induced magnetism. And the strongest magnets are produced by increasing both the amperage and the number of turns. With a given source of electric energy, of course, there is a maximum strength of magnetism which cannot be exceeded. Making the number of turns greater than a certain number would introduce such an additional resistance as to reduce the number of amperes to an equal or even greater extent. The greatest efficiency is obtained when the resistance in the coil of the electromagnet is equal to all the remaining resistance, including the internal resistance of the battery. When only one voltaic cell is used, this maximum efficiency in the production of a powerful electromagnet is obtained by having a number of strands wound together. With a series battery the best results are obtained from a coil consisting of one long single wire, the number of turns being regulated by the voltage of the battery. The amount of power is illustrated by the fact that a horseshoe magnet made from a cylinder ten inches long and half an inch in diameter and around which are coiled thirty feet of wire will sustain a weight of fourteen pounds when acted upon by the current from a single cell, in which there is a zinc surface of only 2½ square inches, and the electrolyte is a thimbleful of dilute acid. In another recorded experiment a cannon weighing 50,000 pounds has been magnetized by a current of 16 amperes passing through 10 miles of wire, making 5250 turns around the cannon. This equaled 110,250 ampere turns. The electromagnet thus produced was so strong that a string of five cannon-balls weighing 250 pounds apiece hung suspended from the cannon by mutual attraction and heavy iron spikes remained in a horizontal position in space. The latter effect was produced when a soldier stood before the muzzle of the cannon with the iron spikes in front of his body. The spikes assumed the direction of the lines of force, and were held pressed against the soldier's body in that position by the enormously powerful attraction of this gigantic electromagnet. A similar observation may be made any time the *x*-ray coil is turned on, if a piece of cardboard is held vertically, separating pens or other light steel or iron bodies from contact with the end of the soft-iron core of the coil. The pens will remain horizontal in the air, one end attracted toward the coil and the other end repelled. This effect is not peculiar to electromagnets—any type of magnet will produce similar effects. An iron or steel rod brought near one pole of a magnet undergoes magnetic induction; the opposite kind of magnetism is generated in the nearest end, and this end is attracted to the pole of the magnet, while the other end of the rod has the same magnetic polarity induced in it as that of the neighboring pole of the magnet, and is, therefore, repelled by it. The strongest effect, of course, is produced by a horseshoe magnet upon a rod placed across its two poles. The end of the armature in contact with the north pole of the horseshoe magnet has south polarity induced in it by the influence of both poles, that kind of magnetism being attracted into it by the north pole and repelled into it by the south pole. It, therefore, has a doubly strong attraction for the north pole of the horseshoe magnet. A similar induction of double strength occurs at the end of the armature in contact with the south pole of the horseshoe magnet. A horseshoe magnet with an armature across its ends will sustain more than two poles of a bar magnet acting separately. It is said to be a polarized armature when the armature itself is a permanent magnet, and, of course, must be made of steel. For most purposes this is less desirable than an armature which is made of soft iron and loses its magnetization when not under the influence of the magnet, and having no permanent polarity of its own, responds fully and freely to the influence of the magnet in every position.

Ganot ("Physics") gives the following as the results of different experiments upon electromagnetic force, and these have varied according to the different senses attached to the term by various observers. Electromagnetic force may mean—(I) the current which the development and disappearance of the magnetism of a soft-iron core induce in a spiral which surrounds it; (II) the free magnetism measured by the action on a magnetic needle oscillating at a distance; (III) the *attractive force*, or the force required to hold an armature at a distance from the electromagnet; (IV) the *lifting power* measured by the force with which an armature is held in direct contact with the pole.

The most important results which have been arrived at are the following:

(i) Using the term electromagnetic force in the first two senses, it is proportional to the strength of the current. This applies only when the currents are not very powerful, and to stout bars; for in each bar there is, as Müller has found, a maximum of magnetization which cannot be exceeded.

(ii) Taking into account the resistance, the *electromagnetic force is independent of the nature and thickness of the wire.* Thus, the strength of the current and the number of coils being the same, thick and thin wires produce the same effect.

(iii) With the same current, the electromagnetic force is independent of the width of the coils, provided the iron projects beyond the coils, and the diameter of the coil is small compared with its length.

(iv) The temporary magnetic moment of an iron bar is, within certain limits, proportional to the number of windings. The product of the intensity into the number of turns is usually spoken of as the magnetic power of the spiral. The greatest magnetizing power is obtained when the resistance in the magnetizing spiral is equal to the sum of the other resistances in the circuit, those of the battery included, and the length and diameter of the wire must be so arranged as to satisfy these conditions.

(v) The magnetism in solid and in hollow cylinders of the same diameters is the same, provided in the latter case there is sufficient thickness of iron for the development of the magnetism. With currents below a certain strength, wide tubes of sheet iron are far more powerfully magnetized than solid rods of the same length and weight; but with more powerful currents, the magnetism of the latter preponderates.

(vi) The attraction of an armature by an electromagnet is proportional to the square of the intensity of the current so long as the magnetic moment does not attain its maximum. Two unequally strong electromagnets attract each other with a force proportional to the square of the sum of both currents.

(vii) For powerful currents the length of the branches of an electromagnet is without influence on the weight which it can support.

Beetz observed that, for the same strength of current, electromagnetism is produced more rapidly in circuits with great resistance and great electromotive force than in circuits with small resistance and correspondingly smaller electromotive force; in the latter case, the reverse currents which occur in the coils of the electromagnet come into play more than in the former.

During magnetization the volume of a magnet does not vary. This has been established by placing the bar to be magnetized with its helix in a sort of *water thermometer*, consisting of a flask provided with a capillary tube. On magnetization, no alteration in the level of the water is observed. But the dimensions vary; the diameter is somewhat lessened, and the length increased; according to Joule, to the extent of about $\frac{1}{270,000}$ if the bar is magnetized to saturation.

As regards the quality of the iron used for the electromagnet, it must be pure, and be made as soft as possible by being reheated and cooled a great many times; it is polished by means of a file, so as to avoid twisting. If this is not the case, the bar retains, even after the passage of the current, a quantity of magnetism which is called the remanent magnetism. A bundle of soft-iron wires loses its magnetism more rapidly than a massive bar of the same size. According to Stone, iron wires may be materially improved for electromagnetic experiments by forming them into bundles and tying them round with wire; these bundles are then dipped in paraffin which is set fire to.

"Remanent magnetism is greater in long magnets—those, that is to say, in which the diameter is small in proportion to the length. It is decidedly greater in soft iron when the magnetizing current is not opened suddenly, as is usually the case, but is gradually brought to zero by inserting successively greater resistances. By suddenly opening the circuit it has occasionally been found with thick rods of very soft iron that a reversed remanent magnetism is met with, which is called abnormal magnetization.

"This is easily understood from the tendency of molecular magnets to revert to their primitive condition. In doing this they experience a certain friction or resistance, and when the magnetization gradually diminishes, this hinders the complete reversal of the molecules; but with a sudden cessation the molecules, from the greater *vis viva* of their reversal, will sooner come back to their original position, or even pass it, and come to rest on the opposite side."

Ampere's Electric Theory of Magnetism.—This theory is that in iron or steel there are electric currents in motion around the atoms or in the atoms, and that when these currents are polarized or all made to flow in the same direction the iron or steel becomes a magnet. Except at the surface, these currents are supposed to neutralize each other. Fig. 87 illustrates Ampere's theory of magnetic induction by an electric current.

Magnetic Inertia or Reluctance.—An expenditure of energy is required to cause all the currents theoretically present in an unmagnetized bar of iron or steel to flow in the same direction and make the bar of iron a magnet, or, on the other hand, to reverse the polarity of a magnet. Both of these processes take time, and so does the return of a soft-iron electromagnet to the unmagnetized state. The magnetic effect is not instantly produced when the electric current is turned on or off, but there is a certain magnetic inertia or reluctance to be overcome. This is of no consequence in the case of an electromagnet which is to be used for some time continuously without a reversal of polarity. The large electromagnet used for the extraction of steel particles from the eyeball is one of this sort. But in the case of the electromagnet which forms the core of the primary coil of an induction coil, it is necessary that the magnetic inertia should be reduced to the lowest possible amount, so as to enable it to become a powerful magnet the moment the electric current is turned on, and then completely to lose its magnetism the moment the current is turned off. The breaking of the circuit may be accomplished by the action of the electromagnet itself pulling the armature away from contact, or it may be done by some extraneous means. In the latter case, the minimum magnetic inertia is required for the proper induction of currents in the secondary by the action of intermittent currents in the primary coil. The minimum magnetic inertia is obtained by making the soft-iron core a bundle of straight parallel wires; and for an x-ray coil, for instance, these wires are about the size of piano wire, and form a bundle two or three inches in diameter, and about twice as long as the spark-length of the coil. Another way of reducing the magnetic inertia is by making the electromagnet of many thin sheets of soft iron bound together, and this is designated as a laminated magnet. The powerful magnets of electric motors are often made in this way.

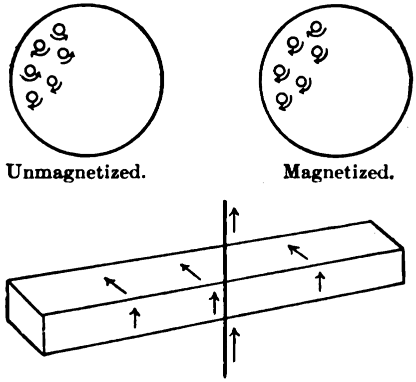
Unmagnetized. Magnetized.

Fig. 87.—Ampere's theory of magnetism. Electric currents about the atoms caused to assume the same direction.

The Properties and Effects of Magnetic Flux.—Electromagnetic waves in the universal ether are what this flux really is. They have the same velocity in free space as light, and are subject to the same variation in velocity when passing through different media. The index of refraction of a substance for light is closely related to its magnetic permeability. The magnetic flux rotates the plane of polarized light if the polarizing substance is in a magnetic field, and it also gives the property of polarization to some substances which do not ordinarily possess it. The Hertzian waves used in wireless telegraphy are electromagnetic waves. The flux from a magnet has the power to produce magnetism in other iron or steel bodies in the neighborhood, without loss of its own power. The magnetic flux also exerts an attraction or repulsion upon such bodies and upon wires through which a current of electricity is passing. Variations in magnetic flux produce currents of electricity in wires in the magnetic field, and this is to-day the most important source of electricity, and is the reason why it has been necessary to state so many of the facts in regard to magnetism.

A coil of wire placed with its turns in a horizontal plane and open at the top and bottom, and traversed by a current of electricity, exerts an attraction upon an iron bar placed within its lumen. The bar may even be held suspended in mid air by the invisible attractive force, not being in contact with any part of the coil, but simply inside the opening along its axis. If the bar is pulled a little distance in either direction, the attraction will bring it back to its position inside the coil. The mutual attraction existing between electric currents and magnets is the force concerned in electric motors and dynamos.

The Attraction Between Electric Currents.—Two active loops of wire freely suspended tend to place themselves in such a position that their plane surfaces are parallel with each other and the currents flow in the same directions. The laws governing the matter are that—
(1) Two currents, parallel and in the same direction, attract each other.
(2) Two currents, parallel but in opposite directions, repel each other.

The north pole of a magnet will be attracted by the end of an active helix which has south polarity, and will be repelled by the end having north polarity.

In the case of either the iron bar or the magnet being fixed and the active coil (wire through which an electric current is passing) being freely movable, the same attraction or repulsion will be operative. And this will cause the active coil to move into such position that the relations between the coil and the magnet or iron bar are the same as if the latter had been movable and the coil stationary. If one active coil is stationary and the other freely movable, the latter will move toward the former if the currents are both in the same direction, or away from it if the currents are in contrary directions.

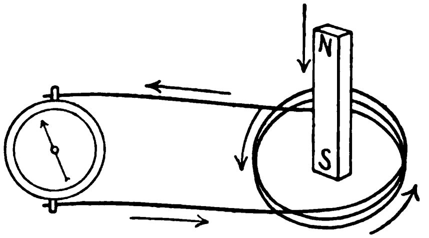

Fig. 88.—Electric current induced by motion of a magnet toward a coil of wire.

Production of Electric Currents from Magnetism.—If one pole of a magnet is brought near a coil of wire which is not connected with any battery or other source of electricity, a current of electricity will be generated in the wire. This may be demonstrated by connecting the two ends of the wire with the terminals of a galvanometer. The arrangement in Fig. 88 illustrates the principle involved. The magnet being moved toward and into the lumen of the coil, a current of electricity will flow through the wire and be indicated by the galvanometer during the motion of the magnet. A current will flow in the opposite direction while the magnet is being withdrawn. No current will flow through the wire while the magnet is stationary either near to or far from the coil. The direction of the current through the coil varies according to which pole of the magnet is near the coil and whether it is being moved toward or away from the coil. The arrows in Fig. 88 indicate the direction of the motion of the magnet and also of the current; and the letters N and S indicate the north and south poles of the magnet. To represent the effect of withdrawing the magnet, it would simply be necessary to reverse the position of all the arrows representing the direction in which the magnet moves and the current flows. Fig. 89 shows the direction of the current produced when the north pole of a magnet is moved toward a coil. And in this case also the direction of the current is reversed if the magnet is moved away from instead of toward the coil.

An electric current is produced at the same moment and in the same direction if the pole of the magnet is moved laterally across the face or end of the coil instead of into it. The current will be in the direction indicated in the last diagram (Fig. 89), while the north pole is moving toward the axis of the coil or the central line passing through the hollow of the coil at a right angle to the planes of its various loops. After the pole of the magnet has moved past the axis of the coil and begins to move away from it, an electric current in the opposite direction is generated in the coil. The currents produced by moving the south pole of the magnet laterally across the face of the coil are the same as those produced by moving the same pole into or out of the coil, as shown in Fig. 89.

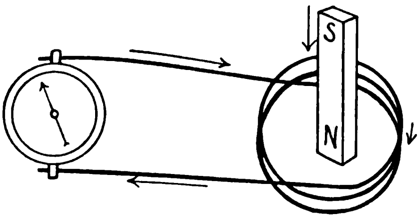

Fig. 89.—Direction of the current when the north end of the magnet is moved toward the coil of wire.

Magneto-electric Machines.—The same currents are generated in all these cases if the coil is moved instead of the magnet, as is the arrangement in the magneto-electric machines (Figs. 90, 91, and 92) which were the predecessors of the modern dynamos and which are still used in therapeutics to some extent. Taking into consideration only one of the coils of wire, as that is rotated toward the north pole of the magnet, a current will be generated in that coil which will be in the direction of the hands of a clock if the coil is viewed from the end facing the magnet. At the same time that this coil has a rotary motion toward the north pole it is moving away from the south pole of the magnet, and the electric current resulting from this is in the same direction. After this coil passes the horizontal line, however, it begins to move away from the north pole and toward the south pole, and the direction of the current flow is reversed, so that a regular alternating current is generated and may be transmitted to a circuit outside of the machine by having the two extremities of the wire connected with two insulated revolving metal collars, against which press two springs or brushes conducting the current to the external circuit. The other coil is receding from the north pole of the magnet at the time that the one

Fig. 90.—Magneto-electric machine for therapeutic use.

first considered is approaching it, and consequently it is necessary that its wire should be wound in the opposite way to make it yield currents in the same direction as those from the first coil. The coils are both connected with the external circuit by the same metallic collars and brushes, and reinforce each other in delivering an alternating current.

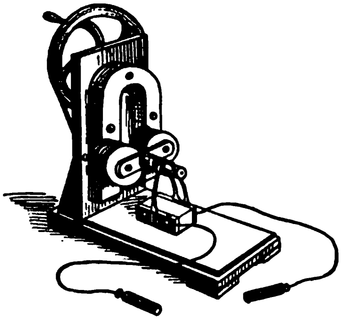

Fig. 91.—Clark's magneto-electric generator, 1500 turns in each coil rotated in front of magnet (laminated).

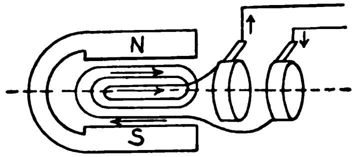

Fig. 92.—Rotated so as to cause upper portion to come toward observer, current would go as shown by arrows. After a half turn it would be reversed.

The Commutator.—This is an important part of any machine for the generation of dynamic electricity by electromagnetic induction. It is a device for converting a series of alternating currents into a series of unidirectional currents passing into the external circuit. In its simplest form (Fig. 93 and 94) it consists in having the wires from the coils terminate in the two halves of a metal cylinder which is completely divided into two longitudinal halves, fastened upon an insulated shaft and rotating with the coils. Each brush leading to the external circuit is in contact with one of the halves of the split cylinder and receives current from it. Calling the sections of the commutator *a* and *b*, and the brushes 1 and 2, the adjustment should be such that during the half revolution that commutator section *a* is positive it should be in contact with brush 1, and when it becomes negative, the connection changes to brush 2. The division between the two halves of the commutator is to be at such a point that the connection with the two brushes changes at the same time that the polarity in the coils changes. While the current in the coils is in one direction, *a* is the positive commutator section and is connected with brush 1, and while the current is in the opposite direction, *b* is the positive commutator section and

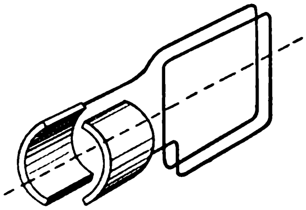

Fig. 93.—Commutator.

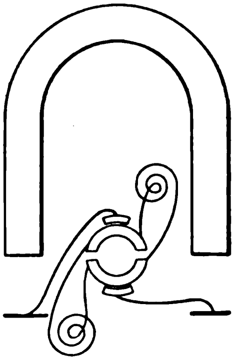

Fig. 94.—Diagram of the commutator in operation.

this is then connected with brush 1. As each alternate current is generated in the coil it is passed through the commutator and brushes in such a way as always to traverse the external circuit in the same direction.

Magnetic Lines of Force or Magnetic Flux.—If a bar magnet is placed flat upon a table and a sheet of paper sprinkled with iron filings is laid over it, the iron filings will assume positions corresponding to the magnetic lines of force. Near the two poles the particles will be most abundantly massed, and will radiate in every direction, while near the middle of the bar there will be few particles, and these will be more or less parallel with the long axis of the magnet. The arrangement of the particles of iron corresponds with the lines of force. These are supposed to be due to ether streamings, both in the magnet and outside of it, set up by the molecular forces at work in the magnet. The lines of force or the magnetic flux leave the magnet at its north pole and enter at its south pole. Of course, it is not limited to the plane of the paper, as is apparently the case in the above experiment, but really completely surrounds the magnet in every direction. This can be seen at once if the magnet is dipped into a mass of loose iron filings. And the direction of the lines of force in the surrounding space can be shown by using fine sewing-needles in the place of the iron filings in the last experiment.

The *direction* of the lines of force is subject to change under the influence of magnetism or electricity. For instance, if two similar magnetic poles, like the north poles of two magnets, are brought near together, the lines of force from each are made to diverge more widely than if one magnet had been there alone. And, on the other hand, the lines of force of both are made to converge and pass from one magnet to the other, forming an ellipsoid if two opposite magnetic poles are brought near together. The attraction of a magnet for other iron or steel bodies is dependent upon the number of lines of force that reach the body to be attracted, and there are two special cases which are to be considered in the construction of electrotherapeutic apparatus. In one class of cases the desire is to produce an attraction upon an iron or steel body at some distance from it, regardless of how many lines of force may be wastefully expended in the surrounding space. Such cases are that of the electromagnet for extracting foreign bodies from the eye, and of the electromagnets used in the vibrating interrupter for the primary currents in induction coils. For this purpose magnets are made of the aëroferric type. This means that the flux passes from one pole to the other partly through air and partly through iron, and the electromagnet is generally made in the shape of a straight bar or bundle of wires surrounded by a coil of wire through which an electric current is flowing, and the polar extremity may even be conic. Leakage flux is the technical designation for lines of force which do not pass through the armature.

To secure the greatest holding power, however, the *ferric type* is required, which means that the magnetic flux or lines of force passing out of the magnet at the north pole traverse only iron on their way to the south pole. This is accomplished in certain cases by making the magnet in the form of a horseshoe, and placing an armature across between the two poles. The horseshoe shape may be only figurative, as in the case of a very useful type of electric motor (Fig. 95), where there is a heavy iron base from which two uprights extend; the latter have large concave surfaces facing each other, and called polar surfaces. Between the polar surfaces and very close to them is the revolving armature of the motor. The stationary part is made a powerful magnet by an electric current passing through coils of wire surrounding each iron standard. It will be noted that it is not necessary that the polar surfaces should be at the ends of the arms of the horseshoe. Except for the small air-space between the polar surfaces and the armature, the magnet represented above is of the ferric type. One of the absolute ferric type is a horseshoe magnet with an iron armature across its ends, and another is an iron ring magnetized by an electric current passing through a coil of wire which surrounds the wire at one part of its circumference. The first of these types of complete ferric magnets is often adopted as a means of guarding against the gradual weakening of a permanent magnet and, of course, is the case where an electromagnet is used to lift or to sustain a heavy weight. The second or closed magnetic ring forms part of the step-up transformer for the induction of high-tension currents in a secondary winding by alternating or interrupted currents in a primary wire; or of the step-down transformer, which induces currents of reduced potential in the secondary wire. For this purpose again the closed magnetic ring may be only figuratively a ring. Very often it is made up of laminated rectangles of soft iron, riveted together at the corners and surrounding a rectangular opening. The closed magnetic ring has a very much higher rate of efficiency in the production of induced currents than has the other type of induction coil with a straight iron core.

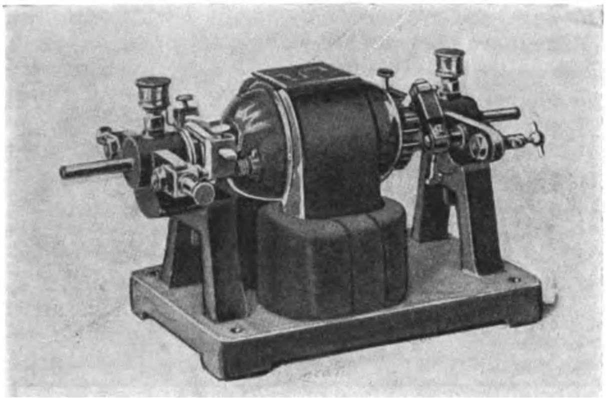

Fig. 95.—Electric motor.

Magnetic flux is the force by which steel and iron are attracted toward magnets, and by which electric currents are generated from the use of magnets. It is proportional to the magnetomotive force, and inversely to the magnetic resistance of the circuit (ferric, aëroferric, or non-ferric) or the magnetic reluctance. The practical unit of magnetic flux is the *weber;* of reluctance, the *oersted;* and of magnetomotive force, the *gilbert.* The formula is $\text{webers} = \frac{\text{gilberts}}{\text{oersteds}}$ or the number of units of magnetic flux is equal to the number of magnetomotive units divided by the number of units of magnetic reluctance. An ampere-turn or a current of one ampere through a single loop produces a magnetomotive force of about 1.25 gilberts. The magnetic flux is strongest when an armature connects the two poles or when the magnet consists of a closed ring, partly because of the fact that in either case the magnetic reluctance is reduced to the lowest possible amount.

A soft-iron core or a closed magnetic ring adds to the efficiency of a coil in producing induced currents, because it adds its own magnetic flux to that directly due to the passage of the current through the primary coil.

The *measurement of magnetic flux* is done by means of a magnetic needle. If the latter is moved out of the line which it assumes under the influence of a magnet and then is released, it will oscillate back and forth before finally stopping at its position of rest. The strength of the magnetic pole is proportional to the square of the number of times that the magnetic needle swings back and forth.

Paramagnetic and Diamagnetic Substances.—All bodies, solid, liquid, or gaseous, are influenced by magnetic attraction. If certain substances, like iron, steel, nickel, cobalt, manganese, or oxygen gas, are suspended between two opposite poles of an electromagnet, they tend to arrange themselves in the line between the two poles, and are called paramagnetic substances. Others, like bismuth, phosphorus, zinc, gold, water, or hydrogen gas, tend to arrange themselves at a right angle to the line passing between the two magnetic poles, and are called diamagnetic substances.

A bar of cobalt arranges itself so that its length is parallel with the lines of force, because it is more permeable to magnetic flux than the surrounding air, and nature always seeks the path of least resistance. It is not because of any north and south polarity on the part of the bar of cobalt.

A bar of some diamagnetic substance like gold arranges itself at a right angle to the lines of force, because it is less permeable than the surrounding air, and the least resistance is produced when the gold forms the smallest and the air the largest possible part of the path traversed by the magnetic flux.

No substance is opaque to magnetic flux. The flame of a candle is diamagnetic, and if held between the two poles of a magnet, it is blown out at a right angle to the line between the poles.

In turning off a heavy current a voltaic arc will sometimes pass across between the two terminals, and unless this is promptly checked, the apparatus may be destroyed or the building set on fire. In situations where this is liable to happen a blower is placed. This is a powerful electromagnet, the flux from which actually blows out the arc passing between the two terminals. This is on quite a different principle from that of the circuit breaker, which is an electromagnet which becomes operative when any excessive or dangerous current is flowing, and shuts off the current by drawing its armature away from a terminal, where it normally completes the circuit. The two devices, however, are sometimes used together.

LIST OF PARAMAGNETIC AND DIAMAGNETIC BODIES.

Paramagnetic.

Iron.
Nickel.
Cobalt.
Aluminum.
Manganese.
Chromium.
Cerium.
Titanium.
Platinum (Wiedemann found pure platinum diamagnetic).
Many ores and salts containing the above metals.
Oxygen gas.

Diamagnetic.

Bismuth.
Phosphorus.
Antimony.
Zinc.
Mercury.
Lead.
Silver.
Copper.
Gold.
Water.
Alcohol.
Tellurium.
Selenium.
Sulphur.
Thallium.
Hydrogen gas.
Air.

The Influence of an Iron Core in a Magneto-electric Machine.—In the apparatus illustrated in Fig. 91, p. 111, each coil has a core of soft-iron wires. The core has a very powerful effect in increasing the amount of current induced in the coil. As one end of the iron core is brought near the positive pole of the magnet it becomes magnetized itself, and that end becomes the negative pole. It has been demonstrated in many different ways that when an iron core inside a coil becomes a magnet, it generates a momentary current in the coil, and another momentary current in the opposite direction when it ceases to be a magnet. If it is a permanent magnet, but varies in power under any influence, then, as it increases in power, it induces a current in the coil, and as it diminishes in power it induces a current in the opposite direction in the coil.

A soft-iron core always has some effect in retarding the change in the polarity of the coil from one phase to another. Its magnetic inertia makes its changes in polarity approach considerably less nearly to the instantaneous than would the changes in the coil alone.

The core adds very much to the amount of inverse discharge in a coil, but this is a subject which need not be discussed until the subject of induction coils is taken up.

Generation of Electric Currents in a Coil of Wire when it Cuts Moving or Expanding or Contracting Lines of Force.—The motion by which the coil is made to cut the lines of force may be a movement of the coil of wire or of the magnet. The same change in their relative position produces the same electric current in the coil. There are many different ways in which the details of this may be varied.

Lenz's Law.—In any case of electrodynamic induction the direction of the electric current produced is such as will tend to oppose the motion producing it. The value of the knowledge of this law is twofold. It enables one to calculate the direction of the current and to construct apparatus consisting of several different magnets, and armatures (coils with or without cores) and commutators and brushes, so as to obtain a combined harmonious effect in the shape of either an alternating or a "direct" current, as may be desired. And, in the second place, it brings us to the explanation of the transformation of mechanic into electric power in the simple apparatus in Fig. 92, p. 111, and in the more complicated dynamos. In any of these machines the mechanic power has to overcome two elements of resistance, one being that of inertia and friction and the other due to the current induced in the coils of wire. The power which is used up in overcoming friction is converted into heat. According to Lenz's law, the current at any moment when the coil is approaching a magnetic pole is such as will cause a force of repulsion between the coil and the magnet. The force required to move the coil through space against this repulsion disappears as mechanic power to be converted into electric power. And the like condition occurs when a coil is being moved away from a magnetic pole: the current induced is such as to attract the coil toward the magnet, and the power exerted in overcoming this attraction and moving the coil away disappears as mechanic power and is converted into electric power.

The Mechanic Equivalent of Electricity.—Just as the mechanic equivalent of heat may be expressed as: 1 pound of water 1° F. = 778 foot-pounds, or it takes 778 foot-pounds of work to raise 1 pound of water 1° F.; the mechanic equivalent of electricity is 1 watt $= \frac{1}{746}$ horse-power, or 1 kilowatt (1000 watts) = 1.34 horse-power. The number of watts produced by a dynamo is found by multiplying the number of amperes by the number of volts. In a well-constructed dynamo of large size about 90 per cent. of the horse-power exerted by the steam engine in running it will reappear as electric energy at the ratio of 1.34 horse-power per kilowatt. In electric motors the process is reversed, and in large motors perhaps 98 per cent., the electric energy passing through the motor as so many amperes at a pressure of so many volts is converted into mechanic power at the ratio of 1 kilowatt = 1.34 horse-power. Small motors are much less efficient, a fractional horse-power motor utilizing only 30 per cent., the rest being lost in friction and other ways.

THE DYNAMO

The name covers a variety of machines for the conversion of mechanic motion into currents of electricity by means of electromagnetic induction.

The essential parts are field magnets, armatures, commutators, and brushes. The field magnets may be stationary, and the armatures made to move past them, or the armatures may be stationary and the field magnets movable.

The **field magnets** are electromagnets or masses of iron or steel surrounded by coils of wire, and which are to a certain extent permanent magnets, or, at all events, retain a sufficient amount of residual magnetism to induce an electric current when the machinery is started. There is then an arrangement by which the whole or a part of the current so produced is made to pass through the winding of the field magnets, and they soon become exceedingly powerful.

The **armatures** are essentially coils of wire, usually with soft-iron cores, which are made to cut the lines of force from the field magnets by their own motion or that of the field magnets, as the case may be. An alternating current is generated in each armature coil, and passes through the commutator, which may or may not convert them into direct (*i. e.*, unidirectional) currents before they reach the brushes from which they pass to the field magnets and the external circuit.

The **commutator,** whose function has been explained on p. 111, is made of rectangular bars of copper surrounding and forming part of the revolving axle in which they are set in insulated slots. Each commutator section is a direct continuation of the wire from one end of the corresponding armature coil, and really forms the termination of it. There is no further path for the current until that commutator section comes in contact with one of the brushes. At that time the commutator section connected with the other end of the same armature coil is in contact with the other brush. And then the cutting of this armature coil through the lines of force of the field magnets induces a current which passes through the armature coil, the commutator, one brush, the external circuit, and the winding of the field magnet, the other brush, the other commutator section, and the same armature coil. The output of a dynamo is a rapid succession of such currents which may pass through the external circuit in the same or alternating direction, according to the construction of the commutator.

The commutator sections are bare upon their external surface, so as to be exposed to complete electric contact with the brushes at the proper time. They are inlaid in hard rubber or indurated fiber, or in some small machines in ivory, which insulates them from each other and from the steel axle of the dynamo.

The **brushes** are in direct connection with the two terminals of the dynamo, and are analogous in function to the collecting combs of a static machine, leading the positive and negative charges to the two poles of the machine. They sometimes consist of flat brass springs which press upon the commutators and come in contact with the different commutator sections and the insulating strips as the axle revolves. In large dynamos the brushes are rectangular pieces of carbon or brass held against the revolving commutator by the pressure of a spring.

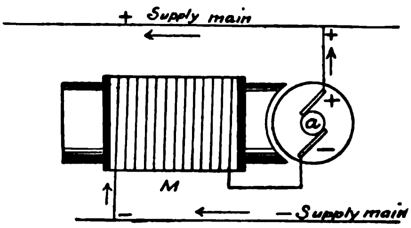

Fig. 96.—Series-wound dynamo

Series-wound and Shunt-wound Dynamos.—A dynamo in which the entire current induced in the armature coils passes through the winding of the field-magnets is called a *series-wound dynamo* (Fig. 96), and this arrangement tends to maintain a uniform strength of current, or the same number of amperes, no matter how great or how small is the resistance in the external circuit. This sort of a dynamo is used when the current is produced expressly for the operation of a number of arc lights connected up in series. The number of amperes which must pass through each arc light is from 6 to 10. The resistance of an arc lamp is such that it takes 42 to 52 volts potential to send this current through one lamp. For a number of arc lamps in series the voltage must be multiplied by the same number, in order to send the same strength of current through the series of lamps. This is accomplished automatically by a series-wound dynamo. Fig. 96 represents a dynamo which is driven by a gas-engine of a certain definite horsepower, and which will cause the armature to revolve at a certain rate of speed when it encounters a certain resistance and at a correspondingly higher rate of speed when the resistance is lessened. With a small number of arc lamps in series the rate of revolution of the armature is such that there is a balance between the mechanic engine and the impedence produced by the currents generated in the armature coils. The latter currents have attractions and repulsions for the field-magnets which are opposed to the motion by which the currents are produced. If the number of lamps were doubled and the resistance in the external circuit were doubled, the increased resistance would tend to lessen the strength or amperage of the current, and lessen the impedence to the motion of the armature by the currents passing through it. The same horse-power being applied from the steam engine, the armature, of course, would revolve faster and a greater potential or number of volts would be produced. The result would be that a new and more rapid rate of revolution would be established, and we should again find that the original number of amperes of current were generated, but with the increased voltage necessary to send that strength of current through the increased resistance. A series-wound dynamo may be called a *constant current dynamo.* This is true up to the capacity of the engine in horse-power. Beyond that the dynamo would fail to drive any current through a series of arc lamps.

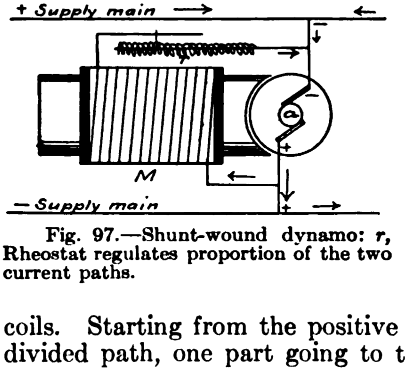

Fig. 97.—Shunt-wound dynamo: *r*, Rheostat regulates proportion of the two current paths.

A *shunt-wound dynamo* (Fig. 97) is called a *constant potential dynamo*, and is designed to yield a current of the same voltage under varying conditions of the external circuit. In such a dynamo the winding of the field-magnets consists of a great many turns of fine wire having a resistance about four hundred times as great as that of the armature coils. Starting from the positive brush, the current passes through a divided path, one part going to the external circuit and the other to the winding of the field-magnets. The return currents from the field-magnets and the external circuit join before they reach the negative brush. The currents which pass through the two different paths are inversely proportional to the resistance in each. If the external resistance is increased, a greater proportion of the current passes through the field-magnets, and this increases their strength and the current output of the dynamo. The reverse takes place when the external resistance is diminished. The result is a uniform voltage, under most conditions.

Compound-wound Dynamos.—These are dynamos in which part of the current to the external circuit passes through the field-magnets and a portion does not. They are designed to yield a uniform voltage under all conditions from no load to full load. The 10,000 horse-power dynamos at Niagara Falls are of this type.

In any dynamo the electromotive force or voltage increases with the speed, the strength of the field-magnets, and the number of conducting loops in the armature.

Gramme's Ring Dynamo.—This is an important type of dynamo, in which a soft-iron ring revolves like a wheel on its axle, its rim being close to the two poles of an electromagnet concaved so as to bring the polar surfaces as near as possible to the ring. The latter has a winding of many turns of insulated wire, making an endless coil around the rim of the wheel. The ring being rotated in the direction indicated by the arrows at the axle in Fig. 98, electric currents will flow through the armature in the direction shown by the small arrows. Commutator sections are arranged to connect with the armature at the points midway between the poles of the magnet, and the one marked + is the positive pole, and the one marked − is the negative pole of the dynamo. The current is "direct," and is almost continuous. As actually constructed for use as a hand generator of electricity (Fig. 99) the magnet is a powerful one of horseshoe shape, and made of laminated steel. The armature consists of thirty coils, each having a large number of turns of fine wire. One end of each coil is connected with the adjacent end of the next coil, and also with a commutator section. The coils thus form a continuous circuit, tapped at intervals by the commutator sections. The armature core is made up of a number of soft-iron wires forming a continuous ring. A hand machine of this kind yields a potential of about three or four volts, which is about the same as is yielded by three or four Daniell cells. The current is a strong one, and a hand machine could be used for cautery purposes or for exciting a faradic coil. But for most electrotherapeutic work the choice lies between a battery, either primary or secondary (storage), and a power-driven dynamo.

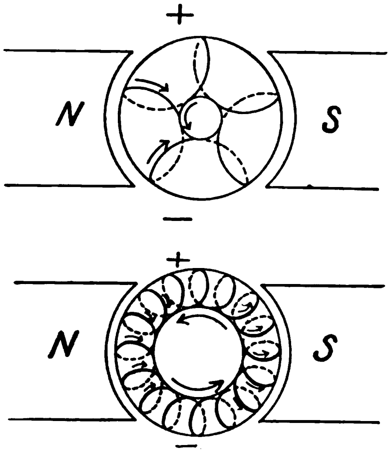

Fig. 98.—Gramme's ring armature in bipolar field.

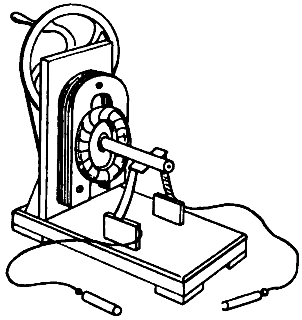

Fig. 99.—Gramme's ring dynamo.

A Dynamo Suitable for a Separate x-ray and Electrotherapeutic Installation.—The apparatus shown in Fig. 100 is a dynamo driven by a gas-engine; both operating upon the same shaft and forming a single machine. The dynamo itself may be independent and operated by a steam or gas-engine or by water power. A two and one-half kilowatt dynamo requires four or five horse-power to run it, and yields a current of 20 amperes and 125 volts. The dynamo itself measures about 30 inches in all three dimensions, weighs about 550 pounds, and makes about 1150 revolutions a minute. This dynamo is designed to yield a direct current of the above amperage and voltage, but dynamos are made to yield various other strengths, and an alternating current if desired.

Motor Generators.—When the current from a dynamo can be obtained, but is not of the required character, it may be made to run an electric motor which in turn produces the rotation of a dynamo and the consequent evolution of an electric current. The complete apparatus is called a motor generator when both parts are mounted at opposite ends of the same axle and revolve as one solid mass. Such an apparatus (Fig. 101) makes it practicable to convert the "direct" 500 volts trolley-car current into a 110 volts current, either "direct" or alternating

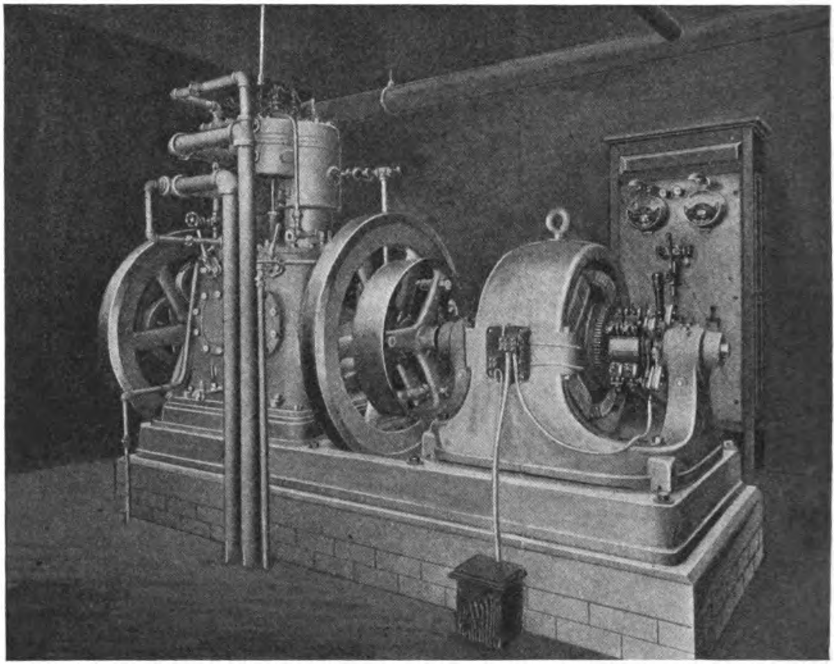

Fig. 100.—Dynamo driven by a gas-engine.

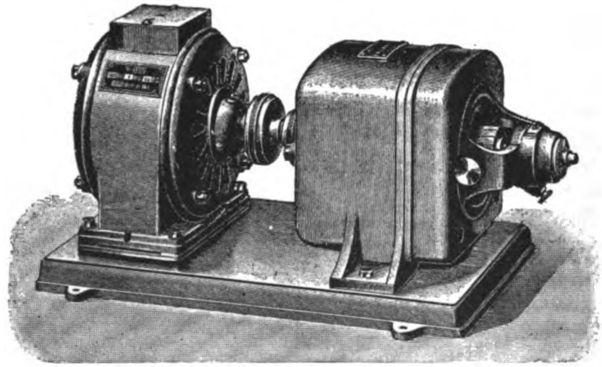

Fig. 101.—Rotary transformer or motor generator.

for electrotherapeutic purposes. It requires very little care, and is turned on and off as readily as an electric light. This is the most practicable type of apparatus for the utilization of the direct current for the operation of the type of x-ray apparatus which, like Gaiffe's, employs a step-up transformer.

Polyphase Currents and Polyphase Dynamos and Motors.—*Polyphase currents* in their practical application were the discovery of Nikola Tesla. They are produced by a dynamo, usually with the Gramme ring type of armature, by making the connections in such a manner that similar alternating currents are sent out through two different sets of conductors at different periods in the cycle of the dynamo. The diagrams represent the production and characteristics of a diphase current. The ring-wound armature is supposed to be fixed between two rotating field magnetic poles placed at the sides, and not shown in the diagram. A current derived from the armature at *a* and *b* would have the maximum strength, and such a direction that *a* would be the positive and *b* the negative pole. Conductors leading from *c* and *d*, the parts of armature at this time in a direct line with two field-magnets, would be devoid of current. As the field-magnets rotate, the current in the conductors *a* and *b* becomes less and less, and that in *c* and *d* greater and greater, until, at an angle of 45 degrees measured from the original position, the currents in both sets of conductors are equal and in the same direction. At 90 degrees the current in *c* and *d* has reached its maximum, and that in *a* and *b* is zero. At 135 degrees the current in *a* and *b* has changed in polarity and is as strong in the new direction as that in *c* and *d* is in the original direction. The latter is diminishing, the former increasing, in strength, and at 180 degrees the current in *a* and *b* has reached its maximum, with *b* the positive and *a* the negative pole, and the current in *c* and *d* has become zero. The remainder of the cycle brings about changes which restore the original condition of the two currents.

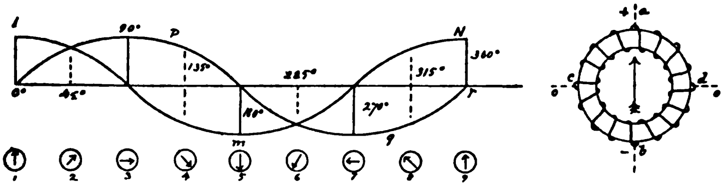

Fig. 102.—Polyphase currents, and Gramme's ring generating them.

A *polyphase dynamo* may be absolutely free from sparks, and may not have any uninsulated surface anywhere. It may be made without commutators or brushes. The field-magnets may be powerful permanent magnets, with completely insulated short-circuited windings, in which currents of the proper direction are induced by the currents in the armature coils. The ring armature is stationary, and the four or more conductors leading from it have soldered connections with its coils, and the whole may be insulated. The points *a* and *b* and *c* and *d* are stationary, but the current flow in consequence of the rotation of the field-magnets is the same as if the armature was revolving and the fields stationary. The same absence of movable contacts and of consequent sparking is found when the polyphase currents are utilized for operating a motor or a rotary converter. It makes electric power available in mines and factories, where the slightest spark would cause a dangerous explosion. Polyphase currents are directly available for the operation of motors, while ordinary alternating currents are not. They are also of the greatest value commercially for the transmission of power in the form of electric currents. The power transmitted is represented by the number of watts or the amperes multiplied by the volts, and since the heating effect upon the wire is practically dependent solely upon the number of amperes, the amount of copper required is much less with a high voltage and low amperage than with a low voltage and great amperage. The transmission of triphase currents at 6600 volts costs less than 1 per cent. as much for copper conductors as the transmission of the same amount of energy over the same distance in the form of a 550 volts direct current. The higher voltage is consequently employed for the transmission of electric power for long distances, as from Niagara Falls to neighboring towns. The insulation must be very complete, first, to avoid expensive leakage of current under this high pressure, and, second, because accidental contact, direct or indirect, with a current of this character could hardly fail to be fatal to animals or men. Indeed, even in the power-house, where this current is converted by transformers and rotary converters into the 500 volts direct current supplied to the trolley line, the workmen are liable to develop obscure nervous disorders. These occur without any accidental contact with the conductors, and are not due to leakage of current, but to the influence of expanding and contracting lines of force. That there should be an effect upon the men is easily understood when we consider the physical and physiologic effects produced by proximity to an Oudin resonator or a D'Arsonval transformer (both of them employed therapeutically), without actual contact or sparking. Accidental contact with the 550 volts direct trolley current may be fatal to men, but is not always so. It usually is to horses, partly on account of their iron shoes, while men are partially insulated. A trolley wire may become an especial source of danger if it comes in contact with a wire carrying the electric arc-light current.

Polyphase currents are useful therapeutically if the proper voltage, amperage, and periodicity are provided. A case will be referred to in greater detail in which progressive muscular atrophy was cured by baths through which triphase currents were passed. This treatment was combined with faradism. The polyphase current is akin to the sinusoidal voltaic current, and they are both an improvement on the direct voltaic current interrupted at irregular intervals by hand for therapeutic purposes.

A Rotary Converter.—This has been alluded to, and is a motor and dynamo combined. It is used for the conversion of one type of current into another, and may be constructed to yield an alternating or a direct current, or a polyphase current, and of any ordinary voltage. But extremely high voltages must be obtained by the use of a step-up transformer.

A small apparatus of this type may be used to produce the sinusoidal voltaic current, and indirectly the sinusoidal faradic currents, which are so distinct an improvement in the therapeutic application of voltaic and faradic currents. But some of the machines which have been constructed for this purpose give a simple alternating current, and not the current whose strength and direction vary, as represented by a sine curve in geometry. In other words, they do not produce a current starting at zero and gradually reaching a maximum in one direction, diminishing gradually to zero and then increasing gradually in the other direction, and then gradually diminishing to zero, as in the apparatus employed by the author. The apparatus alluded to is a combination of a variable resistance and pole-changer actuated by an electric motor (p. 470). The ordinary rotary transformer produces a current which makes more or less abrupt alternations from full strength in one direction to zero, and then again to full strength in the other direction, and is not so suitable for this work. The fault, however, may be remedied by proper construction. What is required for some purposes is a current varying gradually from maximum to minimum, and then with a reversed polarity, each complete cycle taking about two seconds, and the maximum potential being 110 volts; the current strength or amperage to be regulated by a rheostat in circuit with the patient.

Power of Continuous Current Dynamos.—The electromotive force is proportional to the intensity of the magnetic field, the number of turns of wire moving in it, and the speed of movement. The rise is gradual between the two poles. The relation between the electromotive force, the current, and the resistance in the armature in a dynamo obeys Ohm's law.

Power of Alternating Current Dynamos.—Here the relations are somewhat different, it being found, for example, that doubling the speed does not, as a rule, double the current, although it does double the electromotive force and will send the original current through twice as much external resistance.

Dynamos designed to light 500 16-candle power lamps have armatures 10 inches in diameter, and make about 750 revolutions a minute; the current being of 110 volts and 310 amperes. About 70 per cent. of the power employed to run the machine is actually utilized in the lamps. Ninety-three per cent. of the power is converted into electricity, but a certain portion of this is consumed in overcoming various resistances and inductances outside of the lamps themselves.

THE INDUCTION OF DYNAMIC ELECTRICITY BY ELECTRIC CURRENTS

There are two principal ways in which a current of electricity passing through a coil of wire will produce a current in a neighboring coil of wire. In the first place, an active coil or one through which a current is passing may be moved toward and away from the other coil, and excite currents in it just as a magnet would. The same effect is produced if the active coil is stationary and the other moves. In either case the lines of force about the active coil are analogous to those about a magnet, and the currents produced in the other coil are due to the turns in the other coil cutting through these lines of force in consequence of the motion of one or other coil. This method of action is fully illustrated in the dynamos which have been described, and in which the armatures and field-magnets consist of coils of wire which are no less important than their iron and steel cores.

The other principal method is by induction, by which variable currents in one stationary coil excite currents in another stationary coil.

Induced Currents.—It has already been stated that a continuous current passing through one wire does not produce a current in a neighboring wire if the wires are both motionless. But it is a very different matter when the current starts or stops or varies in strength or direction. Every such change in the active wire results in a temporary current in the other wire. The simplest case, and one which shows the principle upon which the entire system of induced currents is founded, is that of two straight parallel wires near each other in the air. When a current of electricity is turned on or begins to flow through the first wire, a momentary current flows through the second wire and in the opposite direction. While the current is flowing uniformly in the first wire, no current flows through the second wire. When the current is turned off in the first wire, a momentary current is produced in the second wire, and this is in the same direction as the current which has just ceased to flow through the first wire. Changes in the strength of the current in the first wire produce similar effects; an increase in current induces a current in the opposite direction in the second wire, while a reduction in current strength in the first wire induces a current in the same direction in the second wire.

An example of the practical application of the induction of currents in parallel straight wires is seen in the process of telegraphing from a moving railway train. In this case the series of dots and dashes in the Morse alphabet are transmitted as a series of interrupted currents passing through a wire fixed along the top of the car. Along the railway is a wire running parallel with the one on the car, and as near as practicable to it. The currents of electricity in the wire on the car induce currents in the stationary wire which actuate telegraphic instruments at any reasonable distance along the line. This is due to simple induction, and is not the same as what has become known as *wireless telegraphy*, and which will be alluded to again in another part of this book.

Induced currents are due to the expanding and contracting lines of force about a wire through which a current of electricity passes. The inducing force is the same as in the case of induction of an electric current by the motion of a magnet; and in this case the relation between the inducing and the induced currents may be very simply expressed as already mentioned.

The following are the *laws of induced currents:*

1. At the instant when the primary current begins to flow or to increase its intensity, an induced current, inverse and momentary, is developed in the secondary coil or circuit.
2. The primary current approaching the conductor gives rise to an induced current in the secondary coil, inverse and momentary.
3. At the moment this current ceases, or when its intensity diminishes, or when the primary coil recedes, an induced current begins in the secondary coil or circuit, direct and momentary.

The Induction Coil.—This is in practical use for a hundred different forms of electrotherapeutic apparatus, as well as for commercial purposes. It consists of a primary coil, a secondary coil, an interrupter, and sometimes a condenser. It is supplied with an electric current by a voltaic battery, a storage battery, or a dynamo circuit, like the electric-light system. It yields a succession of induced currents which are usually of very different potential from the primary current, being of much higher voltage for most therapeutic purposes. And these induced currents are of an alternating character.

The Primary Coil.—The coil of wire through which the current supplied by the battery or dynamo passes is called the primary coil, and the current through it is called the *primary current.* The primary coil usually consists of a small number of turns of rather coarse copper wire, which is insulated by a wrapping of cotton, and which is wound in a single or a few complete layers covering the outside of the bundle of iron wires which form the core of the primary coil. The two ends of this coil are indirectly connected with the battery or dynamo. When the electricity is turned on, the primary current is said to be made; and when the electricity is turned off, the primary current is said to be broken. It will be seen later that the currents induced in the secondary coil occur in consequence of the making and breaking of the primary current, and that they are called, for convenience, the *make and break currents.* The break current is the more powerful, and for *x*-ray work is the only current desired.

Two circumstances in regard to the primary current may interfere with the most effective production of the break current. They are both produced by *self-induction* in the primary coil. This acts especially to induce a break current in the primary, which forms a sort of continuation of the primary current, and is in the same direction; and then again this induced break current in the primary is of higher voltage than the primary current, and causes an electric arc at the interrupter where the current is broken. Both of these circumstances interfere with a sudden and complete breaking of the primary current, and must be overcome or regulated in order to secure the best results.

Self-induction in the primary coil is illustrated very well by the simple coils, without any secondary coil, which are used to light the gas in theaters and other places where it is inconvenient to apply a match to every gas-jet. If the current from a dry-cell battery be passed through a simple coil of wire and then be quickly cut off or broken, a current is generated by self-induction which has such high voltage that it will leap across the spark-gaps at all the different burners and ignite the gas. The original current from one, two, or three cells of a dry battery, if passed through a short straight wire, will produce a tiny, almost invisible, spark across a very small fraction of an inch at the switch as the contact is broken. But if the wire be a long one and made into a coil, the turns of which are insulated from each other, the spark at the switch when the current is broken may be even a third of an inch long. A self-induction coil may be used for the same purposes as a faradic coil, exciting muscular contraction and the other physiologic effects, but it would not be so good or so convenient as an induction coil with both primary and secondary windings. The presence of an iron core adds very much, indeed, to the strength of the secondary current, and it has long been considered a necessary part of an induction coil. This is not the case, however, and recent observations by Lewis Jones show that equally beneficial results with less discomfort to the patient are obtained from a faradic coil without an iron core.

If the self-induction from a small coil and a couple of dry-cells produces spark enough to light a great number of gas-jets, it is easy to understand that the self-induction in a large primary coil like that of an *x*-ray machine, actuated by the current from thirty or forty voltaic cells or a large storage battery or a dynamo, will produce a very powerful spark across the switch when the contact is broken. This will tend to produce an electric arc between the contacts. Arcing at the switch must be prevented because the intense heat will injure the switch and may set fire to neighboring objects. With the heavy currents employed for *x*-ray work the current should never be turned on and off by the ordinary key switch of the electric-light socket. If such a socket is used, there should be an open knife-switch near the coil, and this should always be turned off before the connection is either made or broken at the lamp socket. There is thus no current passing when the lamp socket key is turned on or off, and consequently no arcing there. It is better still to have the feed wires pass directly to the knife switches without the intervention of a key socket. Even at the knife-switch precaution should be taken against the formation of an arc. This will not occur if the switch is opened very quickly, and special switches (Fig. 103) are made to accomplish this. They are closed just like an ordinary knife-switch, but the portion of the blade which engages between the two springs with which it makes a contact is hinged, so that it remains held in position by friction as the switch is opened until the strain on a spring between the rest of the blade and the hinged portion becomes great enough suddenly to draw the latter out from between the two clutches. An instantaneous break like this is not liable to produce an arc. No special arrangement for making a quick contact is necessary. Until the contact is made we have only the 110 volts potential to deal with, and this will not leap across any appreciable space, perhaps only $\frac{1}{100}$ inch, as one metallic connection is brought toward the other. There is no current flowing through the primary coil, and so no self-induction is operative until after the contact has been made. The make spark at the switch which turns on the primary current requires, therefore, no consideration except for the fact that it

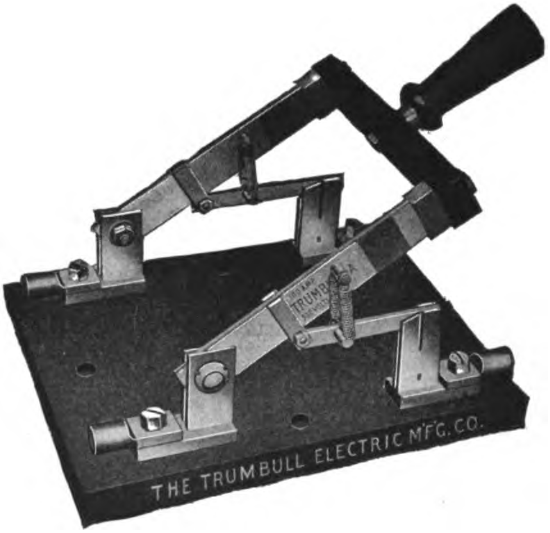

Fig. 103.—Quick break switch for direct current of 75 amperes or less.

will ignite inflammable explosive gases if they are present. The break spark at the primary switch is due to the self-induction in the primary coil, and when the 110 volts current is used to excite an x-ray coil, this spark is a powerful one. It is of importance because of the tendency to produce an arc between the terminals, and this corrodes the two metal surfaces and makes it difficult to press the knife of the switch into the slot between the two springs where the contact is made. It also produces danger of fire, and the switch should always be mounted on a slate or marble base, and care should be taken to keep inflammable substances out of reach. There is the possibility of an arc forming across the whole space when the switch is turned off and the current continuing to flow across the space as an electric arc. This would most effectually ruin the switch by fusing the metallic terminals. To obviate this possibility the terminals should be placed so far apart that it will be impossible to strike an arc between them.

A *knife-switch* intended to turn off and on a primary current of 110 volts and up to 35 amperes should not have a space of less than 1¾ inches between any of its stationary metallic terminals. In practice it is not usually necessary to have a quick break attachment, but it is necessary to have a knife-switch instead of the ordinary key, such as is used to turn an incandescent lamp on and off, and care should be taken to open the switch quickly every time that the current is turned off. In the case of a portable outfit carried to a patient's home and connected with an electric-light socket, an ordinary key receptacle, there should be a knife-switch on the x-ray apparatus, and this should be open while the attachment is made at the electric-light socket. The x-ray apparatus should not be in condition to operate while the connection is being made or broken at the electric-light socket. No current should be flowing when the electric-light key is turned off, and care should be taken to see that the knife-switch on the x-ray apparatus is turned off before the electric-light key is turned either on or off. When this is done, it will be found that the heavy current will be carried all right by a lamp receptacle in which the contacts are good, while it would very probably burn out the contacts to turn a heavy current on or off at this point. Properly used, the lamp socket simply brings the supply of electricity to the knife-switch of the x-ray coil, and it is imperative that the latter should be the place where the current to the x-ray coil is turned on or off.

The same self-induction in the primary produces the little spark which is always seen between the contacts where the primary current of a faradic battery is made and broken. The spark makes it desirable to have the contacts made of platinum or some other metal which is not easily corroded. But with the weak currents employed for this purpose, sometimes supplied by a single dry-cell, no special precautions need be taken except to keep inflammable gases away from it.

The 110 volts direct current, if not interrupted, could be drawn out into an arc several inches long if a current of a good many amperes had been flowing, and if the contacts were separated slowly. The current is practically completely broken by the Wehnelt interrupter, however, and no spark or arc can last more than an exceedingly small part of a second as the switch is opened. A break in the circuit occurs at the platinum point immersed in the liquid, and when a good contact is reëstablished at that point, the metallic contact at the switch has been completely broken. Even though there may be a break spark at the switch from self-induction in the primary, the spark is of only momentary duration when the Wehnelt or other good interrupter is used. With ordinary care about making a quick break one may use an ordinary knife-switch for interrupted currents as strong as 25 amperes, with no other inconvenience than the occasional necessity for filing the contacts smooth where they have been fused.

This does not at all mean, however, that it is safe to turn a current of this strength on and off by means of an ordinary electric-light key. The electric-light socket may carry quite a heavy current if there is a knife-switch at the coil which is turned off both when the electric-light key is turned on and when it is turned off. In this way the electric-light key connects or disconnects the knife-switch with the source of supply, but does not itself turn the current on or off.

Recurring to the subject of self-induction in the primary of an *x*-ray coil, it must be seriously considered in the construction of any type of interrupter for making and breaking the primary current hundreds or thousands of times a minute. With a current strong enough to do the best *x*-ray work, it is difficult to do this by any apparatus which makes and breaks the contact in the open air, although there are interrupters of this type which work well with moderate currents. With the most powerful currents, no open-air interrupter will accomplish the result; there will be arcing, and the current flow will not be interrupted. Generally speaking, the self-induction spark makes it necessary to use either a mechanic interrupter in which the metallic contact is made and broken beneath the surface of some liquid which suppresses the arc, or a liquid interrupter of the Wehnelt or of the Caldwell-Simon type, in which the two metal terminals are always wide apart, and the interruptions are due to an effect of the current itself in flowing through the liquid.

The self-induction in the primary of an *x*-ray coil makes it act like a choke coil. With the same conditions in every respect, except that in one case there is great and in the other little self-induction, the current strength which will pass through the primary coil is markedly greater when there is little self-induction.

A Choke Coil.—If a coil of wire forms part of an electric circuit through which an alternating or an interrupted current passes, the self-induction in the coil may be so adjusted as to impede the flow of the current to almost any desired extent. A coil made for this purpose is called a choke coil. The impedence which it offers is not analogous to friction, as is the impedence offered by a thin straight wire to the passage of a continuous current. In the case of ordinary resistance the reduction in current strength is accompanied by the heating of the conductor and to that extent there may be a loss or waste of power by the conversion of electrical energy into heat. A choke coil, on the contrary, will reduce the amount of current flow by an inductive action without proportionate heating. If ordinary electric resistance is likened to friction, then the impedence offered by a choke coil may be likened to that of an opposing force exerting traction in a direction opposed to the force by which a body is being moved. Where it is applicable, self-inductance is preferable to resistance as a means of reducing or regulating current strength. It obviates the danger of fire and the wear and tear on a resistance coil from the heating effect of the current, and is much more economic of electric energy. Self-inductance so arranged as to produce a choke coil means that in regard to any individual turn when the current is made it induces in all the neighboring turns a current in the opposite direction, and that the mutual relation between the original potential, which tends to send a current through all the turns of the coil, and the counter electromotive force developed by inductance in the turns of the coil is such as to reduce the strength of the primary current to a certain definite extent. Impedence by self-inductance produces a tendency to side flashing. Take the case of a choke coil and a 110 volts interrupted direct current, the coil being so wound that a current of only 11 amperes will flow through it. Then the two wires leading to the coil must be kept wide apart, because there will be a tendency for an induction spark to flash across between them. No such tendency would be noted in the case of a 110 volts interrupted direct current regulated to a current strength of 11 amperes by an ordinary resistance. In fact, in the latter case a much shorter spark will pass between the two wires leading to the resistance than would pass between two loose ends of wire, forming the terminals of the 110 volts circuit.

A choke coil is available instead of a rheostat, or resistance, for regulating the strength of current for an *x*-ray coil, and, in fact, the primary coil of an *x*-ray outfit itself very often performs the function. In the author's 12-inch *x*-ray coil the self-induction in the primary coil when the current (110 volts direct incandescent light current modified by a Wehnelt interrupter) has to pass through the two layers which form the whole length of the primary wire, is much greater than when the connections are made in such a way that the primary current passes through only one layer of the coil. There is quite a difference in the current strength which will be transmitted in the two cases with the rheostat turned to no resistance and only the flat end of the platinum rod exposed to contact with the electrolyte in the Wehnelt interrupter and with a No. 13 Müller tube of the same degree of vacuum in the secondary circuit. With great self-induction the primary current will be only 4 amperes, while the moment the connection is changed to a small amount of self-induction the current increases to 5½ amperes. The increase in current is not due to the lessened ohmic resistance from passage through a shorter length of wire, for there is only about one ohm's resistance in the whole primary coil, and this forms an insignificant fraction of the total resistance in the primary circuit. The difference in current strength is due almost entirely to the difference in the amount of self-induction. When the interrupter is arranged to permit a much heavier current, the difference in self-induction is still more evident, and with the largest self-induction the primary coil acts really as a choke coil, and no matter how much of the platinum point may be exposed, not more than 10 or 12 amperes of current will pass through the primary coil. But with a small amount of self-induction a current of 15 or 20 or even 25 amperes may be made to pass. The author's 8-inch *x*-ray coil has a primary in which three different lengths of wire or numbers of turns may be used, and the variable self-induction obtained in this way offers a valuable means of regulating the strength of the primary current. In fact, with this apparatus, which is a portable one, no rheostat or amperemeter is required. The different lengths of the platinum point exposed to contact with the liquid electrolyte, in the Wehnelt interrupter, and the different amounts of self-induction in the primary winding, regulate the 110 volts direct or alternating current to any desired strength. Of course, it was desirable in the beginning to have an amperemeter in the circuit to measure the current strength with all the various combinations, and a table was made out showing the results.

A separate choke coil may be used to regulate the strength of current supplied to an *x*-ray apparatus by introducing any desired impedence to the passage of the current. It is especially useful with the alternating electric-light current. And when it is separate, it effects a regulation of the current strength without producing variations in the inductive relations between the primary and the secondary coils. A separate choke coil may be used to regulate the current strength and take the place of a rheostat. When different layers of the primary coil, however, are used for a choke effect, we have, besides that effect, a change in the amount of induction in the secondary coil, due to the passage of the primary current through a greater or less number of turns of wire. The voltage of the secondary current depends more than anything else upon the ratio between the number of turns in the secondary coil and the number in the primary coil. And if the latter number is increased, the voltage of the secondary current will usually be diminished, and its volume or amperage will usually be increased.

In connection with the subject of self-induction, it must be borne in mind that two currents of electricity do not flow through the same wire at the same time, either in the same or in opposite directions. Under any circumstances a current of electricity takes place in consequence of a difference of potential at the two ends of the wire, and, other things being equal, the current strength is determined by the difference in potential. The difference in potential is produced by the application of power derived from chemic action in the case of a voltaic battery or of a storage-cell, or from electric or magnetic induction and mechanic motion in the case of induction coils and dynamos. The difference in potential or voltage is an index of the strength of the electromotive force. In the case of a simple wire connecting the two poles of a voltaic battery in operation the electromotive force is a simple force exerted in only one direction and a current of corresponding strength will flow through the wire. But now if another voltaic battery is connected in series with the first battery and the same simple wire, we shall have its electromotive force also operative. If the two are exerted in the same direction, their effects will be added and the current strength will be determined by the sum of the voltage of the two batteries. If, on the other hand, the two batteries are so connected that they would tend individually to send a current through the conducting wire in opposite directions, then the resultant current will flow through the wire in the direction controlled by the battery having the greater electromotive force, and the current strength will correspond to the difference between the two opposing electromotive forces or voltages. The potentiometer for measuring the electromotive force of a voltaic cell or battery employs this principle.

Self-induction may cause a counterelectromotive force tending to produce currents simultaneously with the initial currents, and opposed to them. An illustration of this condition may be found in the case of a force-pump, like a fire-engine, sending water through a hose-pipe and actuated by a constant steam pressure. When the nozzle is at the same level as the pump, the rate of flow will be regulated by the resistance due to friction, and this will depend upon the caliber and length of the hose-pipe. But if the hose-pipe is carried up to the second or third story of a house, a counterpressure is produced by the force of gravity, and the rate of flow will correspond to the difference between the pressure exerted by the steam and that exerted by gravity. The frictional resistance in this illustration is analogous to ohmic resistance, or the electric resistance which can be measured in ohms and which depends upon the electric conductivity of the wire and its length and thickness. The counterpressure due to the force of gravity is analogous to the counterelectromotive force developed by self-induction.

Self-induction may be used to render an intermittent current practically continuous. The break current or the electromotive force induced when the initial current ceases to flow is a powerful one, and is in the same direction as the initial current, and may bridge over the period between one pulsation of the initial current and the next. In such a case the make current or the electromotive force induced when the initial current again begins to flow is in the opposite direction, and reduces the flow of the initial current to some extent. The current flow may, therefore, be practically continuous and of uniform strength. Such self-induction coils are in use in connection with a mercury arc rectifier as part of the apparatus employed for converting an alternating current into a direct current, suitable for charging storage-batteries.

Self-induction Dependent upon the Nature of the Initial Current.—There is practically no self-induction produced by the passage of a continuous current through a straight wire. But when the current is one of an alternating character, especially if of very high tension, the self-induction, even in a short straight wire, becomes so great as to offer an impedence as great as that of an air-space of one or more inches. Under most conditions, if the two terminals of a source of electromotive force are connected with the ends of a short heavy copper wire, every bit of the current will pass through the wire, and even if its ends are bent around so as to be within an exceedingly small distance of each other, no spark will cross that space. But with the modern high-frequency current apparatus for therapeutic use the self-induction developed in the wire offers so great an impedence that the current will flash across a space sometimes as great as 4 inches, instead of passing through a foot or two of a heavy copper wire. This is in spite of the fact that the ohmic resistance of the copper wire may be so slight that it would tranmit a thousand times that amount of power in the form of a continuous current of either high or low voltage.

The amount of reactance or counterelectromotive force due to self-induction is usually diminished by adding to the capacity of the circuit or by the use of a condenser, and this is one reason for the necessity of a condenser in the Ruhmkorff coil.

The total impedence in a circuit is usually made up of the ohmic resistance and the reactance or self-induction, and usually the square of the total impedence is equal to the sum of the squares of the ohms of resistance and the reactance. Thus, if the ohmic resistance is 3 ohms and the reactance 4 ohms, and the current an alternating one of 50 cycles a second, and the voltage 120, the total impedence would be 5 ohms (25, the square of $5 = 9 + 16$, the sum of the squares of 3 and 4). The reactance would be increased by the presenee of a soft-iron core.

The **unit of inductance** is the henry, and equals the inductance of a circuit when the electromotive force induced in it equals 1 volt, when the exciting current varies at the rate of 1 milliampere a second. And if a counterelectromotive force of 1 volt is set up in a circuit when the current is increased at the rate of 1 milliampere per second, then the self-induction of the circuit is equal to 1 henry.

The henry is the unit of induction in all cases, not merely in that of self-induction.

The construction of coils to have a certain self-induction is largely experimental, and the details are different with each different combination of current and apparatus. The primary windings which produce the most desirable amounts of self-induction in *x*-ray coils are described with practical details in the chapter on *x*-ray coils.

The **Oudin resonator** furnishes a most striking example of self-induction. An alternating current of very high tension and high-frequency supplied by an induction coil and two Leyden jars passes through one or two or three or more turns of wire, and beyond one of the terminals the wire is continued in an ascending spiral for twenty or thirty turns. The bare binding posts by which the wire from the Leyden jars are connected with the wire of the Oudin resonator may be touched by the finger without receiving a disagreeable spark. But the effect is multiplied by each turn of wire, and at the free end of the resonator the wire gives off an electric effluve or visible brush discharge, 3 or 4 inches long, and if the finger is brought within 1 inch or so, a powerful stream of white sparks, more or less painful, will be received.

The Interrupter.—A continuous current or one of uniform strength and passing in one direction does not induce a current in a neighboring wire. It is necessary that the current should be made and broken at regular intervals and with greater or less rapidity. For most purposes the rate of interruption is from 1200 to 2000 times a minute. The form of apparatus employed varies according to the strength of the current and the rapidity required.

The Electromagnetic Vibrating Interrupter or Hammer Interrupter.—This is the form almost always employed in connection with faradic coils, and often with Ruhmkorff coils. It may be used with *x*-ray coils, but some other type is usually selected when heavy currents are to be employed. It consists of a disk of iron or steel fastened upon a strip of spring metal, which tends to keep the hammer pressed lightly against a point of contact from which the hammer is drawn away by the attraction of an electromagnet. The moment the contact is broken, the current ceases to flow through the winding of the electromagnet and the hammer springs back to the point of contact again. Each cycle consists in making the current, attraction by the electromagnet, breaking the current, cessation of attraction by the electromagnet, and making the current again. When properly adjusted, such an interrupter begins to act the moment the current is turned on by closing a switch or by immersing the elements in a battery. If it does not start at once, it may be because the point is not in contact with the hammer or because the point is screwed so far forward that even the pull of the electromagnet will not separate the hammer from the point of contact and break the current. This adjustment must be made to enable it to act properly, but even then the interrupter will sometimes fail to start spontaneously, and will require a touch with the finger to start it. This may properly be regarded as a structural defect which should be remedied by the manufacturer. The points of contact on the hammer and on the surface opposed to it should be of some metal which does not easily oxidize, either from exposure to the air or under the action of an electric spark.

The metal strip on which the hammer is fastened may be so made that even when the current is entirely disconnected from the apparatus it will vibrate back and forth for some time before coming to rest. In this case the rate of interruption will be determined to a great extent by the periodicity of the spring itself, just as the periodicity of the hair-spring of a watch keeps it vibrating in seconds exactly the same from the time that the watch is wound up until it runs down. In the case of the watch, the force exerted by the mainspring varies tremendously during this time, but the periodicity of the hair-spring's vibrations continues the same. An interrupter generally has a periodicity of its own, which can be varied so as to produce rapid or slow interruptions in the primary current. This adjustment is sometimes made by turning a screw which advances the point of contact and makes the to-and-fro path of the hammer and its periodicity shorter.

The Ribbon Interrupter.—To secure a very great range of variation in periodicity the vibrating hammer is fastened to a steel band which is held tightly at its two ends, and the tension upon which can be varied by turning a thumb-screw. Its rate of vibration can be changed from a rate so low as to give a coarse, rough, bass sound, by which the interruptions can almost be counted, to a fine, almost inaudible sound, representing almost the highest note perceptible by the human ear. The secondary current, especially its physiologic effects, are greatly influenced by the rate and character of the interruptions in the primary current.

Atonic or Aperiodic Interrupters.—Gaiffe and other manufacturers of *x*-ray coils have fitted them with hammer interrupters in which the hammer will not of itself vibrate back and forth even if started by the finger. This is accomplished by having the pressure of the spring strong enough to prevent a rebound when the hammer is pressed back against the point of contact from which it has been separated and allowed to fly back. Of course, the electromagnet must be strong enough to overcome the pressure of the spring and draw the hammer away from the point of contact. Such an interrupter is designed to be governed by only two forces, the attraction of the electromagnet acting as long as the current flows through its winding and the pressure of the spring. The latter is so adjusted that at no part of its path is there any spontaneous rebound from the point of contact. The spring is never in a position to vibrate back and forth. The point of contact is pressed so far forward that the spring is never allowed to reach its neutral point; it is always making pressure in the same direction, never in the opposite or rebound direction. This is thought to be more absolutely harmonious with the current and to give a better character of interruption for *x*-ray coils than those with an inherent periodicity.

Hammer interrupters may be actuated by the iron core of the primary coil itself, and the contact which they make and break may control the primary current. This is almost always the arrangement in faradic coils, and is sometimes used in small *x*-ray coils. Another arrangement is such that the vibrating interrupter makes and breaks the contact of the primary circuit by its mechanic to-and-fro motion; but it is at a distance from the primary coil, and its own motion is not due to the magnetization and demagnetization of the core of the primary coil. A separate electromagnet actuated by a much weaker current sets this interrupter in motion, and it mechanically makes and breaks the heavy current for the primary coil just as if it were moved back and forth by any other force. The weaker current belonging to the interrupter and its electromagnet is easily and uniformly interrupted, and the uniform to-and-fro motion of the hammer is more assured than if it depended upon the complete interruption of as powerful a current as that of the primary of an *x*-ray coil. The hammer goes back and forth, regularly touching and withdrawing from the point of contact where the primary current is made and broken; and this regular motion is independent of the primary current, and goes right on, even if an arc forms temporarily across the space and the primary current thereby fails to break for the time being.

The Wheel Type of Electromagnetic Interrupter.—This is shown in the appended diagram (Fig. 104). The contact is broken at *c* by the mechanic motion of the hammer, and this is produced by the pressure and relaxation of the eccentric, *e*. The latter is fastened to a revolving wheel whose four spokes are permanent magnets. When the contact is made at *c*, the current flows and the core of the primary coil becomes a powerful electromagnet, exerting an attraction for the magnet whose opposite pole is near it, and a repulsion for the magnet whose nearest end has the same polarity as that existing at that end of the iron core. These forces start the wheel in rotation, and the eccentric presses against the spring metal support of the hammer, breaking the contact at *c*. Momentum carries the wheel around to a position where the contact is again made and where the same magnetic forces again become operative, giving the wheel a fresh impetus in the same direction. It is a simplified type of electric motor, and produces a very rapid and uniform interruption of the current. The currents used for faradic coils are not strong enough to require such an elaborate interrupter, and it will not work well with the heaviest currents used for *x*-ray work. It has proved useful, however, in apparatus for the production of high-frequency currents, and one such interrupter is reported to give an excellent output of

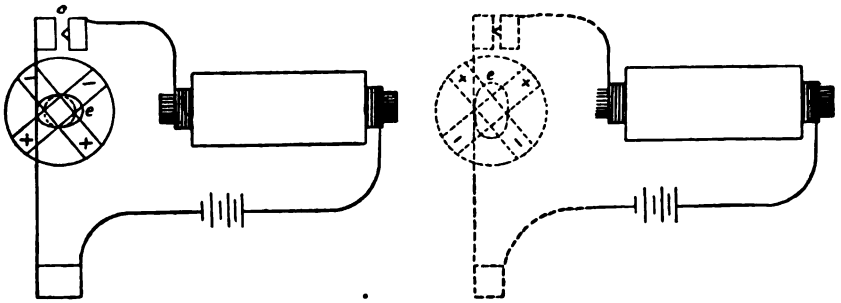

Fig. 104.—Wheel interrupter.

100 to 500 milliamperes, with a primary current of 1 ampere or considerably less.

All the interrupters described above depend upon the alternate magnetization and demagnetization of an electromagnet, these causing to-and-fro movements in the armature which mechanically make and break the current in the electromagnet and in the primary coil. These two are sometimes the same and sometimes separate coils of wire.

Mechanic Interrupters.—There are also interrupters which make and break the primary current by means of the motion of one of the points of contact, this motion being produced by a motor of some kind which acts quite independently of the current which it is designed to control. The arc which tends to form when the points of contact are separated would allow the current to continue to flow across that space. It is usually suppressed in these interrupters by having the points of contact below the surface of a liquid, such as alcohol. The contacts may be like those of the revolving commutator of a motor or dynamo, or the contact may be between liquid metallic mercury and some solid metal. Mercury interrupters are of two types—the mercury dip and mercury jet interrupters. All these except the Leduc interrupter are of use chiefly for high-frequency currents and the *x*-ray, and are described in the section upon the latter subject (p. 802).

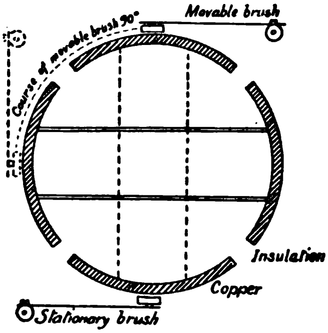

Fig. 105.—Leduc's interrupter.

Leduc's Interrupter.—Our diagram (Fig. 105) shows Stephan Leduc's modification of the Contremoulin interrupter. It consists in making one of the brushes movable, and thus enables one to regulate the fraction of the total period of the interrupter, during which the two brushes shall be in contact with the same pair of metal strips. This fraction can be varied from a very small fraction ($\frac{1}{1000}$), up to the full time represented by the length of the metal strip. No current can pass through the interrupter when either brush is in contact with the insulating substance or when the brushes are in contact with metal strips belonging to different pairs, and therefore having no metallic connection with each other. To produce a contact lasting only a very small fraction of a period the movable brush is placed in such a position that the one metal strip only begins to touch it as the opposite strip is just leaving the other brush. To produce a contact lasting for the maximum time the brushes are placed directly opposite each other, and in this position one brush is in contact with a certain metal strip the entire time that the other brush is in contact with the connected metal strip. Intermediate positions of the movable brush allow the current to pass during a larger or smaller fraction of each period. Knowing the fraction of each period that the current is flowing and the tension of the current as shown by a voltmeter in shunt, we can calculate the quantity of electricity passing through the patient or the apparatus. Then, again, an aperiodic galvanometer, which is called a dead-beat milliamperemeter, in the circuit will show the quantity of electricity passing, this being indicated in milliamperes and being actually the average rate of flow of the current, including the portions of time when the current is interrupted. If the rate of revolution is rapid, the periods occupy a shorter length of time, but there are more of them in a minute and the current strength remains the same. Very great variations in the rapidity of the interruptions produce changes in the physiologic effects, even though they do not change the average current strength.

In regulating the fraction of each period occupied by the duration of the contact we may depend upon the graduated scale marked upon the apparatus. But if this is defective or is absent, the adjustment becomes a matter of calculation. In order to have a contact $\frac{1}{10}$ of each period, close the circuit with a non-polarized resistance and raise the tension by adjusting the volt controller, for instance, until the milliamperemeter shows, for example, 10 milliamperes. Start the interrupter and shift the movable brush to such a position that the milliamperemeter shows that a current of 1 milliampere is passing. Really this means that a current of 10 milliamperes is passing for $\frac{1}{10}$ of the time, and consequently $\frac{1}{10}$ of each period. The proper position of the movable handle for other fractional currents is found in a similar manner. Stephan Leduc has estimated the time during which the current passes even to so small a fraction as $\frac{1}{300,000}$ of a second of time.

Liquid or Electrolytic Interrupters.—These are used chiefly in *x*-ray and high-frequency work, and are described on p. 800.

The Secondary Coil.—This is a coil containing a very large number of turns of very fine wire which is very carefully insulated. The wire itself in an *x*-ray coil is No. 36; looks as fine as a hair; is wrapped with silk; and is coated with melted paraffin after being wound in the secondary coil. The secondary coil in a 12-inch *x*-ray coil contains 40 miles of wire. The secondary coil in a faradic battery contains from 1000 to 8000 feet, the larger number of feet corresponding to the faradic coil with fine wire, the 1000 feet corresponding to the faradic coil with coarse wire in the works of some authors.

In a great *Ruhmkorff coil,* made by Apps for Spottiswood, there were 280 miles of wire. It gave a 42-inch spark through the air when actuated by a voltaic battery of 30 Grove cells. Since the discovery of the *x*-ray, coils of this power have frequently been made.

Every time the current is made or begins to flow in the primary coil a current is induced in the secondary coil. This is momentary, and flows in a contrary direction to that of the current in the primary coil. When the primary current is broken or ceases to flow, a current is induced in the secondary coil which is momentary, and in the same direction as the current which has just ceased to flow in the primary coil. The break current is direct and produces a more powerful discharge across an air-space or through a vacuum tube than does the make current. The latter is what is spoken of as the inverse discharge in *x*-ray work. There is thus a distinct polarity to the secondary current. Although it flows first in one direction and then in the other the greatest effect is produced during the periods when a certain pole of the coil is the positive. This can be seen in *x*-ray or in any other vacuum tube work, and a difference can even be seen in the sparks passing across from one pole of the secondary coil to the other. The negative end of the spark is much brighter and of a violet-white color, while the positive end is not so brilliant and has a more reddish tinge. And then, again, the successive sparks, each of which can be seen as a complete more or less zig-zag line, are more divergent at the positive than at the negative pole. A photograph made of a series of sparks passing between the two similar blunt metal terminals of a 12-inch x-ray coil shows that the majority of the sparks start from the same spot on the positive terminal and pursue the same path for a certain distance, then separate, to converge again on approaching the negative pole, but no two paths coalesce, and they all reach different parts of the surface of the negative terminal. The result is entirely different, however, when one electrode is conical and the other is a flat metal plate (Fig. 106). What has been said, however, is not intended as a statement that the spark originates at one pole and terminates in the other pole. It is probable that the discharge takes place simultaneously from both terminals.

By the *negative pole* of the secondary coil is meant the one which is the negative pole during the break or direct discharge. This is the pole which is always connected with the cathode or negative electrode of an x-ray tube, and an important part of x-ray technic is the suppression of the inverse discharge. In another part of the book (p. 685) will be found a description of the means adopted to prevent the inverse discharge from passing through the x-ray tube in sufficient amount to be a disturbing factor. The only useful current supplied to an x-ray tube is the direct discharge which is produced in the secondary coil by the break of the primary current. The inverse discharge which occurs alternately with the direct discharge is produced by the make of the primary current. During the inverse discharge the polarity of the secondary coil is just opposite to what it was during the direct discharge, and the current may be said to pass through the x-ray tube in the wrong direction. Under normal conditions the x-ray tube appears divided into a brilliantly fluorescent half in front of the plane of the platinum disk or anticathode, and a dark hemisphere behind that plane. When there is a good deal of inverse discharge, but still considerable direct discharge, the whole tube appears lighted by a streaky or irregular greenish fluorescence. There is sometimes a great deal of inverse discharge and scarcely any direct discharge. This condition is indicated by the absence of the illuminated hemisphere in front of the plane of the anticathode in place of which there is a dark hemisphere with only one bright green spot where the cathode ray, starting from every spot on the platinum surface, strikes the glass wall of the tube and generates x-rays. The half of the tube which should be dark is irreg-

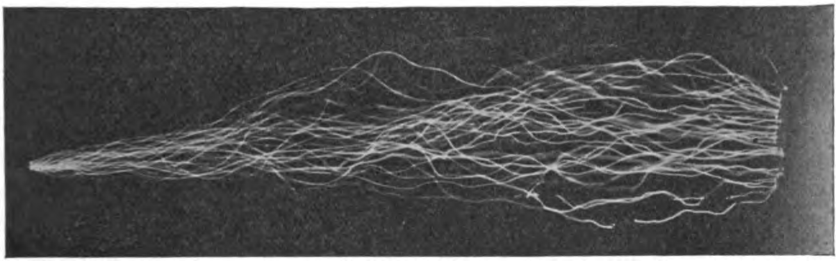

Fig. 106.—Sparks passing in one-eighth second between terminals of author's 12-inch x-ray coil. Single path at pointed and multiple paths at plate electrode regardless of polarity.

ularly fluorescent from similar cathode rays originating from other parts of the anticathode or from the accessory anode. The tube in such a condition looks like a tube connected with the wrong poles of the coil. We cannot secure any useful *x*-ray from a tube of the usual model during the make or inverse discharge of the coil. The best that can be done is to prevent any considerable part of this inverse discharge from passing through the tube, and thus to secure the greatest efficiency during the alternate periods when the direct discharge is passing through the tube. The importance of the subject lies in the fact that any conditions which permit the passage of the inverse discharge through the tube obstruct to about the same extent the passage of the direct discharge and reduce the output of the tube. In the extreme case mentioned a few lines back, and which the author can duplicate experimentally at any time, no effective *x*-ray at all is produced. The wear and tear upon the tube are excessive.

The *wire* in the secondary coil is almost as fine as a hair, and the object of this is to bring every turn of it as close as possible to the primary coil, so as to cut as many of the expanding and contracting lines of force as possible. It is not sufficient that the secondary coil should be outside of the primary coil, it must also be very close to it. The secondary winding for one of the smaller induction coils for faradic treatment is not a difficult matter. The difference in potential between one end of the long secondary wire and the other is not sufficient to produce a spark of any appreciable length, and so the ordinary methods of insulation are sufficient. The insulated wire is wound upon a reel, just as thread is wound upon a spool, one layer after another, all continuous and all in the same direction. The insulated beginning and end of the wire are both left outside, where they can be connected with the binding posts, to which may be attached the conducting cords leading to the patient. These binding posts are of metal, and are fastened upon an insulated base of varnished wood, hard rubber, ivory, indurated fiber, marble, or slate. The regulation of the strength of the current passing to the patient is sometimes secured by changing the primary current, by changing the resistance, or by changing the number of cells if a voltaic battery is used. It is much better, however, to have the primary and secondary coils so mounted that their relative position may be varied. The strongest secondary current is produced when the secondary coil entirely covers the primary coil, and as the primary coil is drawn out from the lumen of the secondary coil, the secondary current becomes gradually weaker. Measuring the distance in centimeters that the movable coil is displaced enables one to use a mathematic number in recording the strength of the current applied to the patient. The quality of the secondary current varies according to the number of feet of wire in the secondary coil and the rapidity of the interruptions, and it will be seen (p. 452) that very different physiologic and therapeutic effects may be obtained by means of such variations.

The *soft-iron core* has always been considered an important part of an induction coil. Its effect is to increase the strength of the secondary current by adding its own expanding and contracting lines of force to those of the primary coil. It is best made of soft-iron wires in a straight parallel bundle. These acquire and lose their magnetism when the primary current is made and broken much more promptly and completely than a solid bar of the same weight. The strength of the secondary current is very considerably augmented. As already stated p. 125), the core is not a necessity, and recent observations indicate that for faradic treatments the current has a pleasanter quality if there is no core.

The Condenser.—This is not required with a liquid interrupter of the Caldwell-Simon or Wehnelt types, but is required with any of the vibrating or other mechanic interrupters. It is made for an induction coil, of a great many layers of tin foil separated by mica or paper, and is usually concealed in the wooden base of the coil. The sheets of tin-foil are in two separate sets, and fit together like the two halves of a pack of cards when one half is held in each hand and the cards are being shuffled by pressing them together in an interlocking fashion. All the sheets of one half are fastened together by one metal clamp, and they really form a single large metal coating or armature of a condenser in which the other armature is formed by the other sheets of tin-foil, and the glass jar or plate is represented by the many sheets of mica or paper which prevent any contact between the sheets of tin-foil in one set with those in the other set. The condenser is designed to prevent excessive sparking at the interrupter, and in this way to produce a sharper and better break of the primary current than would be possible if the primary current continued to flow as an arc across the space after the contact was broken. The condenser takes up or absorbs the extra current, which results from self-induction in the primary coil at the moment that the circuit is broken. We have already seen (p. 126) that this extra current is of high tension, will spark across a considerable air gap, and has in this way some of the properties of static electricity. It very naturally occurs that when the two armatures of the condenser are connected with the ends of the wire forming the primary coil in which such a current is generated, the condenser becomes charged. The effect at that moment is the same as when the inner armature of a Leyden jar is brought in contact with one prime conductor of a static machine, while the outer coating touches the other prime conductor. In the case of the induction coil the charge received by the condenser produces just so much less tendency to sparking at the interrupter. The high electromotive force generated at the time of the break of the circuit ceases, and the condenser becomes discharged as its outer and inner coats are connected by the primary wire. It is then ready to perform its function at the next break in the primary current.

Liquid or "electrolytic" interrupters do not require any condenser to suppress the spark when the current is broken. There is a tremendous difference between the conductivity through a complete liquid path and the resistance offered by the mass of incandescent vapor which is generated at the narrowest part of the liquid path. This results in a practically complete obstruction to the flow of even the high-voltage extra current occurring from self-induction in the primary circuit at the time it is broken.

The **general arrangement of an induction coil fed by a voltaic battery** is shown in Fig. 107. *b* is the voltaic battery. From one pole of the battery a wire leads directly to *p*, where it is continuous with the primary coil of wire. The other end of the primary wire is shown in the diagram at the opposite end of the coil, but in actual practice both ends of the primary wire are usually brought to the same end of the coil. The other end of the primary wire leads to the base of the vibrating hammer, *h*, which, when no current is being used, is pressed lightly against the contact *k* by the springiness of its metal stem. From *k* a wire leads to the other pole of the battery when the switch, *dl*, is closed. Wires lead from the two ends of the primary wire to the two armatures of the condenser, *c*. When the current is turned on by changing the switch from *dm* to *dl*, the current passes through *k* to *h*, and through the stem of *h*, and a connecting wire to one end of the primary, through the primary wire, and thence to the other pole of the battery. The soft-iron core *i* becomes a powerful electromagnet and attracts the hammer *h* away from the contact *k* and breaks the current. This break is accompanied by the induction of a high-tension extra current in the primary which surges out through the conducting wires, most of it going to the condenser where such large electric capacity is provided. Set screws not shown in the diagram regulate the pressure of the hammer upon the contact while at rest, and also the distance that it can go when drawn away from it. In no case is it necessary for it to touch the iron core. Motion toward the magnetized iron core is in a direction to break the current, and no electric contact is required to be made at that end of its path.

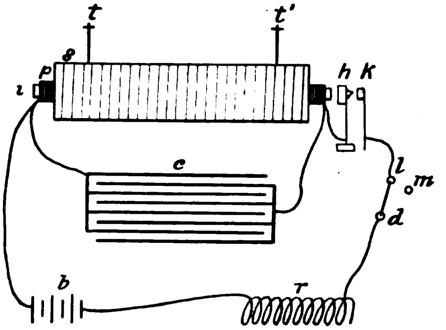

Fig. 107.—General arrangement of an induction coil fed by a voltaic battery.

The secondary coil has its two terminals leading out and connected with binding posts. The smaller induction coils are called faradic coils, and conducting cords lead from the two terminals to electrodes, which are applied to two different parts of the patient. In the case of the very large Ruhmkorff coils, suitable for *x*-ray work, a spark or an actual flame may pass across between the two terminals, when a full current is turned on, unless the two terminals are connected with an *x*-ray tube or some other apparatus through which the secondary discharge is conducted. This is because of the enormously high voltage or difference in potential between the electric charges at the two ends of the forty miles of wire forming the secondary coil. The charge is developed thousands of times a minute; its duration is only momentary, but during its continuance there is an almost irresistible tendency for the two opposite forms of electricity, positive and negative, to rush together and become neutralized. The tension at the two poles or terminals is so great that a succession of sparks will pass across the 12 inches of air-space which separate them, although every inch requires a voltage variously estimated at from 10,000 to 30,000. If not quite enough current is turned on to produce a spark across that distance between the poles, a brush discharge of violet light, accompanied by a crackling sound, will take place into the air surrounding the two poles. In either case a spark will fly to the finger or any other conductor brought near either of the poles, and the same is true even when the discharge is passing through some apparatus to which both poles are connected. This property possessed by high-tension electricity of sparking across an air-space or through any other insulating substance to a neighboring conductor has to be constantly borne in mind in the therapeutic and also in the industrial application of electricity. It is the cause of most of the accidents occurring to human beings in power-houses and elsewhere, and is often the cause of explosions and fires occurring in connection with the use of electricity for light and power. It must be guarded against in the construction and manipulation of electrotherapeutic apparatus, to prevent puncturing *x*-ray tubes and burning out induction coils. Fortunately, there is nothing dangerous about the sparks or shocks which may occur from handling electrotherapeutic apparatus. At the same time they are disagreeable, and should be prevented by care in manipulation.

The difference in potential between any two parts of the secondary wire varies according to their relative position in the series of turns that make up the coil. Imagining it for the purpose of explanation as a single spiral layer of wire wrapped around a very large glass cylinder, the difference in potential between the wire at the two ends might be 150,000 volts, or sufficient to spark across an air-space of 12 inches. The difference in potential between any two consecutive turns, on the contrary, would be very small. Roughly speaking, it would be the total voltage of the coil divided by the number of turns. In the same way the difference in potential between any part of the wire is equal to the same fraction of the total voltage that the number of turns of wire between these two parts forms of the total number of turns. If the two ends of the wire are bent around, so as to be brought within 12 inches of each other, a spark will pass between them even through the air. But it is quite different with two consecutive turns of wire, between which the difference in potential may be so slight that an ordinary silk wrapping will prevent any passage of electricity from one to the other, even if they are wrapped one on top of the other. The difference in relative position has reference to the distance between them following the continuous wire from end to end. It has no reference to the physical position of the turns. They might be wound in such a way in making the coil that two turns lying in physical contact with each other might be portions of wire many thousands of turns apart if the wire were followed. The difference in potential between the extreme ends of the secondary wire is so great that the terminals cannot both be placed at the same end of the coil. If they were, there would be sparking across from one to the other and also from the poles to intervening turns of wire, and one of the latter sparks would ruin the coil by destroying the insulation of the wire at that place in the coil. For the same reason the secondary coil cannot be wound in successive layers, each continuous from one end of the reel to the other, like a spool of thread. With such an arrangement portions of the wire many thousands of turns apart would be placed in such close physical proximity that a disruptive discharge would pass from one such turn to another and ruin the coil.

The form of winding which has been adopted for *x*-ray coils consists in having the wire in several flat spirals, separated from each other by disks of hard rubber. Each flat spiral contains consecutive turns, and between the beginning and end of that section there is not enough difference in potential to break through the insulation of silk and wax and cause a short circuit. The additional insulation afforded by the hard-rubber disk is sufficient to prevent a discharge occurring between one section and the next adjacent one, in spite of the considerable difference in potential. Sections near the ends of the coil have an enormous difference in potential, but a discharge is prevented from occurring, first, by the physical distance between them; second, by the insulating properties of the mass of wax in which the whole coil has been boiled and is embedded, and, third, by the insulation of the numerous hard-rubber disks. The whole coil is in the form of a hollow cylinder built up over a tube of micanite, a compound of mica and shellac, which forms the best possible insulator. This should be long and thick enough to prevent a discharge passing from one end of the secondary coil to the primary coil, and through that to the other end of the secondary coil. The resistance in the primary coil is very small, and its position inside the secondary coil and extending from one end of it to the other would make it offer a short circuit for the secondary discharge if the primary coil were insufficiently insulated. The completed *x*-ray coil consists of a secondary coil and a primary coil which has no connection with the secondary coil, but lies loosely in the micanite tube lining the secondary coil. The primary coil may be pushed in or out or may be removed entirely. The secondary coil is sometimes incased in marble and sometimes in hard rubber, and these are desirable safeguards against the passage of a discharge to some intermediate part of the secondary coil from the discharging rods often connected with its two poles. Such a spark would ruin the coil.

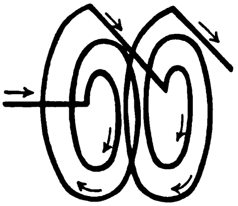

Fig. 108.—A correct winding, but impracticable.

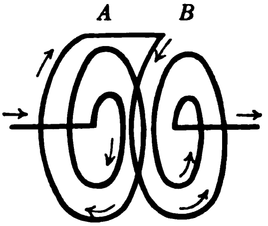

Fig. 109.—Incorrect winding.

In building a coil up in disks, like sections of wire wound between hard-rubber disks, it is necessary that the wire in each section shall be continuous with that in the adjacent sections, and that the direction of the current shall be the same in all the sections. For instance, looking at the end of the coil, if the current in the first section passes in the direction of the hands of a watch at a certain period, then the current in all the other sections must pass in the direction of the hands of a watch at the same period of time. The connection between the first section and the second may be made by passing the central end of the first spiral wire through a hole in the hard-rubber partition near the central end of the adjacent spiral wire. When it comes to joining the other or outer end of the second spiral, it is passed through the outer part of the next hard-rubber partition and soldered to the outer end of the next spiral. So the different sections which have been wound separately are united into a single continuous wire, but there is a very necessary precaution to be taken in securing the proper direction of the current in each of them. If they are all strung along on the axis of the coil, so that they are all, for example, right-handed spirals, as in Fig. 109, *A*, and *B*, the current in each section would be flowing in an opposite direction from that of the adjacent sections. The reason is very simple: if the current in one is flowing from the outer end of the spiral wire to its inner end, it is continued in the next section from the inner to the outer end of the spiral wire; and if they are all right-handed spirals, the current in one is in an opposite direction to that in the next spiral. The current in each section is not merely flowing through the wire, but is actually excited in that section; and in the bad arrangement shown in Fig. 109, it would completely neutralize and arrest the current excited in the opposite direction in the adjacent section.

Fig. 110 shows the proper arrangement of the various sections. There are right-handed and left-handed spirals alternately, and the current flows in the same direction in all. The picture is purely diagrammatic. Each spiral really is a disk-like mass containing thousands of feet of wire, and its flat surface is separated from that of the adjacent section by only the thickness of a hard-rubber disk. The arrows show the direction of the current at the time when the terminal near *A* is the negative and that near *C* the positive pole of the secondary coil.

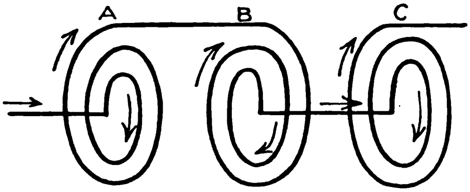

Fig. 110.—Best method of winding secondary sections in an induction coil.

The arrows would all have to be reversed to show the direction of the current during the period when *A* is the positive and *C* the negative pole. In the last few paragraphs we have spoken of the direction of the current, and it might have been called the direction of the electromotive force. The make or, especially, the break of the primary current induces an electromotive force in every individual turn in every section of the secondary coil; and if the latter is correctly constructed, all these electromotive forces are added together in series and the result in voltage is perfectly enormous, just as it would be if a tremendous number of voltaic cells were set up in series. The current which will spark across between the terminals or which will pass through a vacuum tube or other apparatus connected with the two poles is of great voltage and of very small amperage. The power possessed by the discharge from the secondary coil is expressed in watts, one watt being equal to 1 ampere of current at 1 volt of potential. The total number of watts equals the number of amperes multiplied by the number of volts, and no more power can come out of an induction coil than was put into it. The intake, in a typical case, may be 6 amperes at 10 volts, making 60 watts, and the resulting secondary current may have a voltage of from 100,000 to 300,000. Supposing all the power of the 60 watts in the primary current were converted into power as the secondary current, then we might have the following equation: 100,000, the number of volts in the secondary current, multiplied by the number of amperes in the secondary current, equals 60, the number of watts, 100,000 (x amperes) = 60; $x = \frac{60}{100,000}$; $x = \frac{6}{10,000}$; $x = \frac{6}{10}$ of a milliampere. This $\frac{6}{10}$ of a milliampere would be found to be the maximum intensity of the secondary current, except for the fact that the primary and secondary currents are interrupted, and that the secondary current is of an alternating character with wide variations in intensity. The number of watts as a maximum must be reduced materially, because the induction coil wastes some of the power put into it. There are certain lines of force leaving the two ends of the iron core and arching over from one end to the other which are not cut by the secondary turns of wire. This is true of any aëroferric type of magnet. It will be seen on another page that this loss of power is prevented in transformers of the closed magnetic ring or complete ferric type. There is some loss of power or reduction in the number of watts yielded by an induction coil on account of the ohmic resistance of 200,000 feet of fine wire. This loss would be evident as overheating of the secondary coil, except for the fact that the ohmic or frictional resistance is in proportion to the intensity or amperage of the current, and not at all to the pressure or voltage. A certain number of watts of electric power in the form of a current of 100,000 volts and $\frac{6}{10}$ of a milliampere will pass through a wire without perceptible heating, whereas the same 60 watts of power as a current of 10 volts and 6 amperes would heat the wire white hot and perhaps vaporize it. The ohmic resistance in the secondary coil is great enough, however, to make a material difference between the number of watts applied to and the number yielded by an induction coil. But this output or secondary current has wide variations in intensity at different parts of each of its 2000 to 10,000 cycles a minute. At a certain instant there may be a powerful current in one direction; at another instant no current may flow, and at another instant there may be a powerful current in the opposite direction. A milliamperemeter in which each unit indicates a milliampere ($\frac{1}{1000}$ ampere) may be used to measure the strength of the secondary current. It may be connected with one pole of the coil and with the *x*-ray tube and register in this way the intensity or amperage of the current passing through the tube. This will appear to be from 0 or even a minus quantity up to 2, 4, 6, 8, or even 15 to 40 milliamperes. The latter represents a tremendously powerful current which no *x*-ray tube will stand for more than a few seconds. The milliamperemeter may be of the D'Arsonval type, and depend upon the directional effect of a current passing through a coil which is in close relation with a powerful magnet. In such a case, the needle upon the dial indicates in a general way the average strength and direction of the secondary current. The alternations from the direct to the inverse discharge are so rapid that they are not shown by such an instrument. Such a meter may indicate 0 when the *x*-ray tube is giving a radiance by which quite a good picture may be made, and this would indicate that the inverse discharge was equal to the direct. The value of this type of milliamperemeter as a guide to the proper application of the *x*-ray is considered at another place (p. 807). Enough has been said, however, to show that this type of meter often indicates a strength of secondary current a great many times in excess of the $\frac{6}{10}$ milliampere, which with 100,000 volts would equal the maximum of 60 watts power in the case under consideration. This is manifestly misleading.

A *hot wire milliamperemeter* between one pole of the coil and the *x*-ray tube gives a reading of several milliamperes, and is not influenced by the amount of inverse discharge. This, again, seems to show many times more power leaving the induction coil than is put into it, and this is misleading. In an experiment by the author a large hot wire milliamperemeter intended to measure high-frequency and high-tension currents up to 650 milliamperes intensity was connected with one pole of a 12-inch *x*-ray coil. A wire fastened to the other binding post of the milliamperemeter reached to within a few inches of the other pole of the coil. The 110 volts direct current of the incandescent electric lighting system, after passing through a Wehnelt interrupter, produced a current of 6 amperes in the primary coil. A regular flame passed across the 4 inches separating one pole of the coil from the wire leading to the milliamperemeter. The length of the spark showed a voltage of 50,000 or 100,000 and the milliamperemeter indicated an intensity of 150 milliamperes. Here there was an apparent power of 10,000 or 20,000 watts produced by the application of about 600 watts, the major part of which was certainly expended in overcoming the resistance in the liquid interrupter. This is also misleading.

Spottiswood's Induction Coil.—This was a great coil made in 1876, and some of the facts in regard to it will be of interest. It was 48 inches long and 20 inches in diameter. The primary coil was of copper wire, $\frac{1}{10}$ inch in diameter and 2000 feet long. It made 1334 turns in six layers. The secondary coil contained 240 miles of wire in four different sections; 2 of wire $\frac{1}{100}$ inch in diameter, and two of a little larger wire; the total number of turns being 342,000. A battery of 5 galvanic cells produced a 28-inch spark; 10 cells gave a 36-inch spark, and 30 cells a spark 40 inches long.

IRON CORES

Spottiswood's Great Coil by Apps.	Diameter of Wire, Inches.	Outside Diameter of Core, Inches.	Length, Inches.	Weight, Pounds.
......	No. 1, .032	3.56	44	67
......	No. 2, .032	3.81	44	92

PRIMARY COILS

Diameter of Wire, Inches.	B. W. G.	Length, Yards.	Resistance, Ohms.	Weight, Pounds.	Conductivity, Per Cent.
0.096	13	660	2.3 0.181	55	93
0.096	13	504	0.211 0.231	84	93

SECONDARY COIL

Length of Coil, Inches.	Method of Winding.	Diameter of wire in Inches.	B. W. G.
42	1344 turns in 6 single layers. 3 pairs of double-strand layers.	Central part, .0095 Outside part, .011	32 31

Length, Miles.	Resistance, Ohms.	Conductivity, Per Cent.	Length of Coil. Inches.	Outside Diameter, Inches.
280	110,200	94	37.5	20

CONDENSER

126 sheets tin-foil, 18 inches × 8¼ inches, separated by two thicknesses of varnished paper, .011 thick, 19 inches × 9 inches surface.

BATTERY

5 one-quart Grove cells, plates 6¼ inches × 3 inches, gave 28-inch spark with smaller primary.
10 one-quart Grove cells, plates 6¼ inches × 3 inches, gave 35-inch spark with smaller primary.
30 one-quart Grove cells, plates 6¼ inches × 3 inches, gave 42-inch spark with smaller primary.

The secondary discharge is seen, from the above examples, to consist of a succession of waves in alternate directions, of extremely high voltage and of an amperage much greater than is produced by a static machine and much greater than could be maintained by the same power as a continuous current of the same voltage.

The Undulatory Nature of the Induced Current.—A tracing made by means of Duddell's oscillograph shows that the current from an induction coil usually consists of a series of separate curves, each beginning suddenly at a distance from the neutral line and descending or ascending more or less gradually toward it. Fig. 111 shows the kind of a curve made by the secondary current of an induction coil with a short secondary winding and a soft-iron core. The break currents are seen below the neutral line and the make currents above it. In the case illustrated the make currents are not so powerful, but last much longer than the break currents. The latter are of short duration and of abrupt character. According to the observations of Lewis Jones,[1] such a current produces a much more disagreeable effect in causing muscular contraction than one illustrated in Fig. 112 produced by the same coil after withdrawing the soft-iron core. Even this, according to Lewis Jones, is not ideal; there is too great a difference between the make and break currents, and a still greater uniformity would be better for diagnostic purposes. This uniformity can hardly be obtained from an induction coil, but is produced by the right character of interruptions in a continuous current and in a circuit with little self-induction. He uses this current, which is considered on another page 476) under the name of the interrupted voltaic current instead of the faradic current, for diagnosis and treatment.

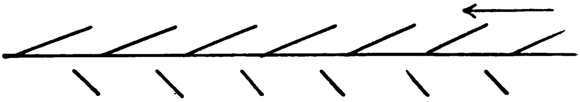

Fig. 111.—Secondary currents from induction coil with iron core.

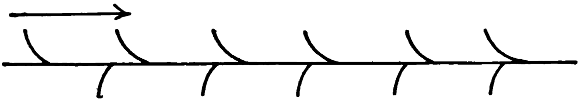

Fig. 112.—Secondary currents from coil without iron core.

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[1] British Medical Journal, October 8, 1904.

Before leaving the subject it will be best to reproduce two more of Lewis Jones' graphic representations. Fig. 113 shows the character of an interrupted and reversed voltaic current in a circuit with little self-induction. For a certain period of time the most favorable being $\frac{1}{1000}$ of a second, the current strength is uniform and in the same direction. Then a change occurs almost instantaneously and a similar period follows with the current in the opposite direction. With a proper interrupter the frequency of these cycles and the duration of the successive currents may be measured and regulated.

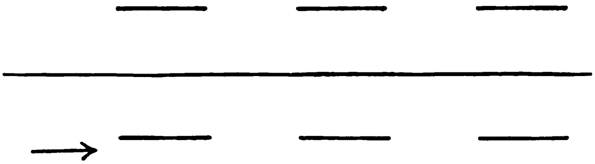

Fig. 113.—Leduc currents. Interrupted and reversed voltaic currents in a circuit with little inductance.

The influence of self-induction in such a circuit is shown in Fig. 114, where a few hundred turns of wire are introduced in the circuit. The result is that the current strength gradually increases from zero until its increase is cut short by the break and reversal of the current. The same sort of a curve in the opposite direction represents the current during the alternate period. There is scarcely a demonstrable interval between the two periods of current flow. This form of current also could be used as a substitute for the faradic current from an induction coil.

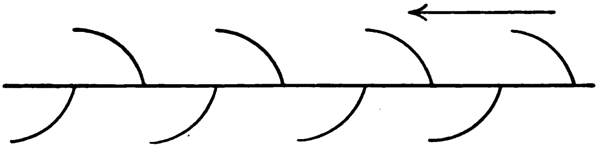

Fig. 114.—Interrupted and reversed voltaic currents in a few hundred turns of copper wire.

Fig. 115 shows the primary and secondary currents in an induction coil with a long secondary wire and without an iron core. The upper line shows the primary current with its abrupt rise when the contact is made, its continuance at a certain strength up to the instant that the current is broken, and its sudden fall at that time. The lower diagram shows the secondary current; the curved lines, the make currents above and the break currents below the heavy neutral line. The differences between the two different currents in the secondary coil are important. They are in opposite directions. They attain

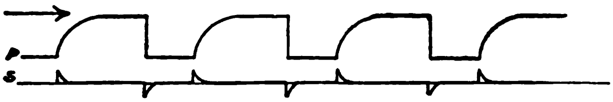

Fig. 115.—Currents in an induction coil with a long secondary wire and no iron core: *P*, Primary; *S*, secondary.

a maximum almost instantly when the primary current is made or broken, and very soon cease. The make current is not so strong as the break current, but lasts longer and dies out somewhat more gradually than the break current. In this particular experiment the make current of the secondary coil lasted $\frac{1}{500}$ of a second, and the break current $\frac{1}{800}$ of a second, the frequency of the interruptions in the primary current was 80 times a second.

It is necessary to have a separate electromagnet if a hammer interrupter is used with an induction coil which possesses no iron core. The ribbon vibrators as used in faradic coils, and usually actuated by the magnetized iron core, are equally desirable for separate use in this case. It is noteworthy, however, that no vibrating interrupter is perfect. They all fail occasionally to make a perfect electric contact, and this may occur at irregular intervals and produce a disagreeable effect upon the patient.

The duration of flow of each secondary current should be about $\frac{1}{1000}$ of a second to produce the best effect in exciting muscular contractions.

Fig. 116 shows the primary and secondary currents in the same coil with a long secondary winding, but with a soft-iron core introduced into the primary coil. The primary current shows the effect of the additional self-induction. There is a choke effect when the current is made, and as this induced counterelectromotive force in the primary coil disappears, the primary current gets stronger and stronger right up to the time that the contact is broken. The effect of this upon the secondary current, which is the current applied to the patient, is shown to be very marked. The make current attains its maximum less suddenly and dies out very gradually, lasting right up to the breaking of the contact. The break current is a great deal stronger than without an iron core, and is of about twice as long duration. This is quite characteristic of the current from a faradic coil, and according to several observers it occasions more discomfort in the production of muscular contraction in diagnosis or treatment than does the current from the coil without a core, or than a simple low-tension current interrupted rapidly with or without alternations. Besides being more or less uncomfortable, it is very difficult to make any accurate measurement of the current passing through the patient. Tracings like those in the preceding paragraphs are to be made only with the most elaborate apparatus and preparation. Practically, one is limited in using an ordinary faradic coil to depend upon the sound of the interrupter for an indication of the rate at which the successive currents occur, and upon the length of the secondary coil and its distance from the primary coil to indicate the strength of the secondary currents. No measure-

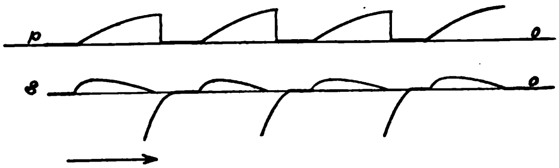

Fig. 116.—Currents in an induction coil with a long secondary wire and an iron core: *P*, Primary; *S*, secondary.

ment and no adjustment are practicable at the time of the treatment of the strength of each impulse of the secondary current, and of its duration as compared with the pauses between the make and break currents; in other words, of its actual duration and the fraction of each period occupied by it.

The hammer or vibrating interrupter is another source of imperfection in the ordinary faradic coil; a tracing of the currents will show that many of the contacts are ineffectual, and that there is a corresponding irregularity in the secondary current. Of course, a better interrupter may be employed for the primary current, such as one which the present author calls the commutator type of interrupter. The Leduc interrupter (p. 137) is an example, and this will correct the irregularity in the current; but it yields such a desirable interrupted voltaic current that the induction coil would not be required at all. The effect of the iron core may be minimized by slipping a metal tube over it. This cuts the expanding and contracting lines of force as the core becomes magnetized and demagnetized, and whatever energy is consumed in producing electric currents in the metal tube loses its direct effect upon the secondary current.

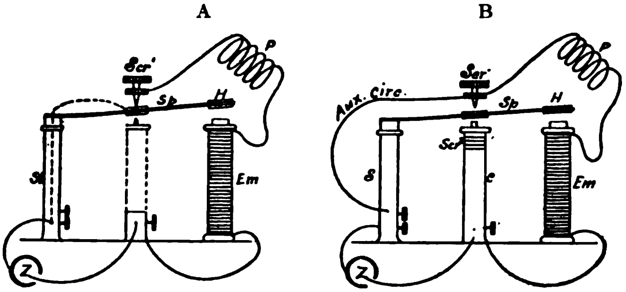

Fig. 117.—Faradic coils: A, Ordinary arrangement. B, Helmholtz's arrangement. Wagner or Neef's hammer interrupter for Bois-Reymond slide faradic coil, two different arrangements: *St*, Standard; *S*, Helmholtz column; *Em*, electromagnet; *P*, primary coil; *H*, hammer; *Scr*^{1} and *Scr*^{2}, upper and lower contact screws; *Sp*, spring; *Aux. circ.*, auxiliary circuit.

Helmholtz's Faradic Coil.—This is an arrangement by means of which the secondary currents in each direction are made approximately equal. In the ordinary arrangement the make current is weak, impaired by the self-induction in the primary coil, which causes the primary make current to increase less abruptly than it otherwise would, and hence to be less effective in inducing a secondary current. And in the ordinary arrangement the self-induced extra current in the primary coil at the break is immediately stopped by the fact that the circuit is open. It may produce a spark at the interrupter, but it has little effect upon the primary current, which ceases quite abruptly and produces a strong "break" current in the secondary. These conditions are shown in the diagram Fig. 118. The heavy line shows the actual course of the primary current as modified by the influence of the extra current almost exclusively at the make. Except for the latter the primary current would have followed the rectangular path marked "desideratum" at the make.

The ordinary arrangement of the vibrating interrupter of a faradic coil is shown in Fig. 117, A. Starting from the zinc pole of the voltaic cell, the current finds only a single path through the standard *St*, the spring *Sp*, the contact screw Scr^1, the primary coil *p*, the electromagnet *Em* (the primary coil and the electromagnet may be the same or may be separate and in series), and back to the other pole of the voltaic cell. When the current is made by contact with the screw Scr^1, there is but a single conducting path, as above described, and when the contact at that point is broken by the attraction of the electromagnet for the hammer, the current is completely cut off.

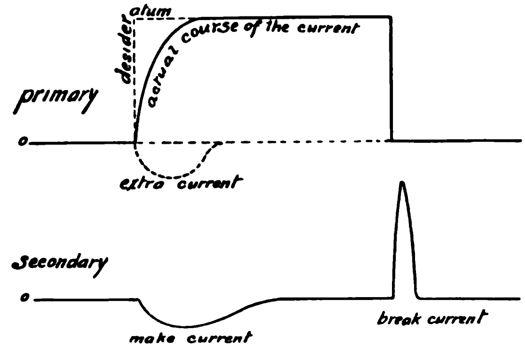

Fig. 118.—Faradic currents with ordinary Wagner hammer interrupter.

In Fig. 117, B, it will be seen, on the contrary, that at this stage the primary coil is short-circuited, and this permits of the full establishment of the break extra current in the primary. At this stage the primary coil is. disconnected from the zinc pole of the battery. The extra current circulates in a complete circuit, consisting of the primary coil, the electromagnet, the Helmholtz column and the wire leading to it, the spring of the interrupter and the auxiliary circuit through the contact screw Scr^1 to the primary coil. Through this circuit the battery current is completely cut off, but the extra current flows in the same direction, and this reduces the secondary current produced by the break in the same way and to about the same extent as is the case with the make secondary current.

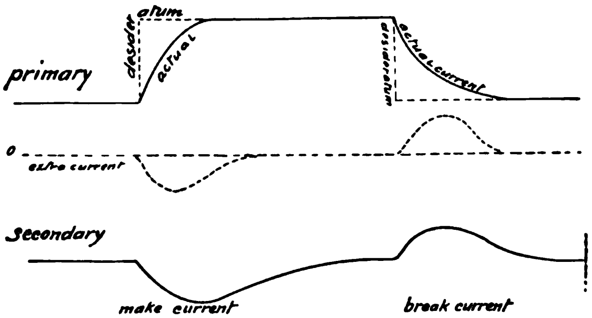

Fig. 119.—With Helmholtz's arrangement.

To be accurate, the current through the primary coil is increased or diminished, not made or broken, by the Helmholtz type of electromagnetic interrupter; and while the induced currents are approximately equal, this is accomplished by reducing the break secondary current to about the strength of that occurring at the make (Fig. 120). The inductive effect is, therefore, a weak one, and to secure the usual faradic strength of application it is necessary to use a primary battery yielding seven or eight volts. An extra resistance in the battery circuit will generally be found necessary with this type of interrupter.

There is a growing belief that the faradic current, with its high-tension discharge, is not so good even in its own particular field of an excitomotor as the rapidly interrupted voltaic current. The faradic coil, however, is of so simple and inexpensive a construction and is operated by so small a supply of current that it will long continue in use where an inexpensive and readily portable apparatus is required to simply excite muscular contraction, as in the treatment of paralysis.

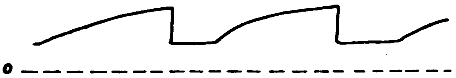

Fig. 120.—Usual type of primary waves in faradic coil.

One of Lewis Jones' experiments shows the effect of great frequency of interruption in a faradic coil with an iron core, and consequently a long duration to the make and break currents in the secondary coil. This is illustrated in Fig. 121, where we see the make current suddenly cease and change to the break current. The break current is "treading upon the heels of the make current." The lower line in this diagram represents the make current and the upper line the break secondary or induced current.

The importance of the character of the interruptions in any current which is applied directly to the human body lies in the fact that muscular contractions do not occur during the passage of a continuous current, or one which is uniform and flows in one direction. They are usually excited by variations in the strength or direction of the current or by making and breaking the current, and in this way remind one of the way in which electric currents are induced in one coil of wire by currents in another coil. With interrupted currents the greatest effect in exciting muscular contraction is produced when the current flows during a large fraction of each period. This has been tested by Lewis Jones, who found that a potential of 22 volts was the weakest that would excite muscular contraction when the current flowed only $\frac{1}{1000}$ of a period, or as there were 100 periods a second, only 0.00001 second; whereas seven volts would produce the same muscular contraction if the current flow was increased to $\frac{100}{1000}$ period, or 0.001 second. Further consideration of this topic is reserved for another part of the book (p. 476).

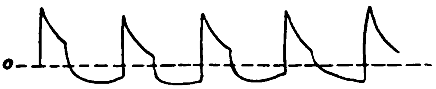

Fig. 121.—Incomplete waves in the secondary coil when there are too rapid interruptions in the primary.

THE CHARACTER OF THE ALTERNATING ELECTRIC-LIGHT CURRENT

The current flows with its full strength in one direction for about half the time, and with its full strength in the other direction for about half the time. The time which elapses between the beginning of one flow in a given direction and the beginning of the next flow in the same direction is called a cycle. A 100-cycle alternating current is one which makes 100 complete cycles every second. The 60-cycle current is one very commonly employed. Each cycle includes a certain time of flow, first in one direction and then in the other; and at the end of each a time of change to the opposite direction. This transition takes only an incredibly short time, but still is made by gradations which, of course, are exceedingly rapid. The current through an alternating electric-light circuit of 100 incandescent lamps would make a tracing like that in Fig. 123. During the time represented by the line *a–c*, and which is about $\frac{1}{200}$ second, the electric current is flowing in one direction with an intensity of 50 amperes. Another way of stating this is that during this time the quantity of electricity passing through the wire is at the rate of 50 coulombs per second. The latter way of expressing the rate of flow enables us to compare the alternating electric current with the flow of water during the rise and fall of the tide. The $\frac{1}{200}$ second during which the electricity is flowing in one direction at the rate of 50 coulombs a second corresponds to the six hours or so during which the tide is of full force up stream and the water is flowing at the rate of 50,000 gallons an hour. At *c* in Fig. 123 the electric current becomes very rapidly reduced to 40, 30, 20, 10 amperes, and to zero, and then begins to increase with equal rapidity to a strength of 10, 20, 30, 40, and 50 amperes, which it reaches at *d*. From this point to *e* the horizontal line represents $\frac{1}{200}$ second, during which the intensity of the current is 50 amperes, and at the end of this time a change occurs by which

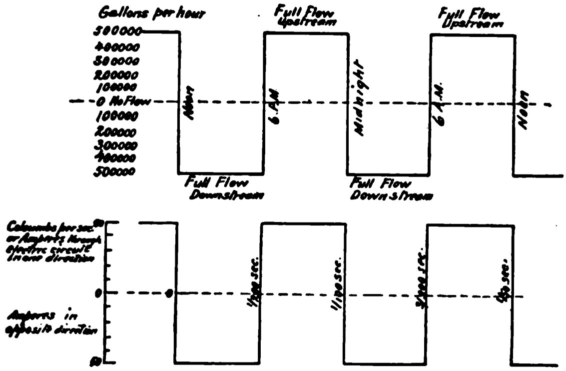

Fig. 122.—100-cycle alternating current.

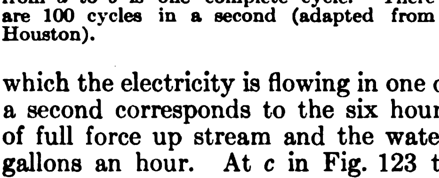

Fig. 123.—100-cycle alternating current from *a* to *b* is one complete cycle. There are 100 cycles in a second (adapted from Houston).

the direction of the current is again reversed, and at *b* we have completed one cycle of this alternating current. The change from one direction to the other occupies an exceedingly short space of time, and this fact is expressed, though not quite correctly, by representing it as a vertical line in the diagram. As to the effect produced in various therapeutic applications, these transitions are so abrupt that the current may be regarded as completely interrupted as well as reversed at each alternation. For our purpose, then, this current may be represented as in Fig. 124, by a series of disconnected horizontal lines, alternately above and below the neutral line. Each line *a–c* or *d–e*, represents a current of the full strength, 50 amperes in this particular case, for $\frac{1}{200}$ second in one direction or the other. *a–c* and *d–e*, constitute the two parts of the complete cycle *a* to *b*. A current of the character indicated in Fig. 124 is an extremely effective one, both in inducing currents in other wires and also in producing physiologic effects. Its potency in the latter particular makes it a much more dangerous current to handle at high voltages than the direct current of the same voltage, but when the alternations are more rapid than 5000 times a second the current ceases to produce muscular contraction and acquires the properties associated with high-frequency currents.

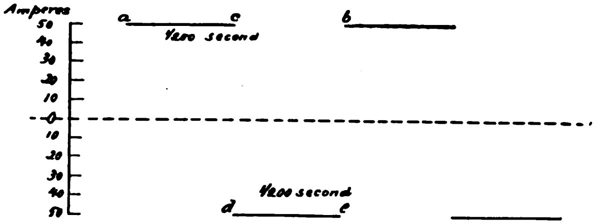

Fig. 124.—100-cycle interrupted and reversed voltaic current; 5 to 15 milliamperes would be suitable for electrotherapy.

Forms Under Which the Alternating Current is Used in Medicine.—In its original unmodified form it is used for diagnostic illumination, phototherapy, electric baths, and for the induction of high-tension currents for *x*-ray and high-frequency currents, and for the induction of low-tension currents for cautery purposes, and to run electric motors for various purposes.

It may be altered by various devices or, rather, its energy may be utilized so as to produce a direct current, a sinusoidal current, a polyphase current, or any other desired form.

Alternating Current Transformers, Step-up and Step-down Transformers.—The alternating electric-light current, with its change from, say, 50 amperes in one direction to 50 amperes in the other direction every $\frac{1}{200}$ second, is an ideal one to induce secondary currents. This is all the more true because it has been found that no accessory apparatus is required, simply a primary coil and a secondary coil, both surrounding a soft-iron core. The principle is the same as in the induction coil, but the variations in the current are supplied ready made by the dynamo, and no interrupter is needed and no condenser or other contrivances, such as are necessary in the case of an induction coil. The secondary currents are of any desired voltage, dependent upon the number of turns in the two coils. If there are twice as many turns of wire in the secondary coil as in the primary, the voltage of the secondary current will be twice that of the primary current. Or, if the secondary has only $\frac{1}{100}$ as many turns as the primary, the secondary current will be of only $\frac{1}{100}$ the voltage of the primary. A very important fact, also, is that the amperage of the secondary current undergoes equal but opposite variations, so that in proportion as the secondary current increases in voltage it diminishes in amperage, and vice versâ. The same amount of energy is generated in the form of a high-tension current of low amperage or of a low-tension current of great amperage. The best transformers yield a secondary current whose energy is equal to 97 per cent. of the energy required to send the current through the primary coil. The simplicity of the apparatus, two insulated coils with an iron core, which requires no moving parts, and the fact that it can be constructed to transform the 110 or 220 volts alternating electric-light current into a low-tension current of great volume for cautery purposes, or a high-tension current of small volume for *x*-ray and high-frequency applications, makes the transformer exceedingly valuable. The heating effect of the current is dependent upon its volume or amperage.

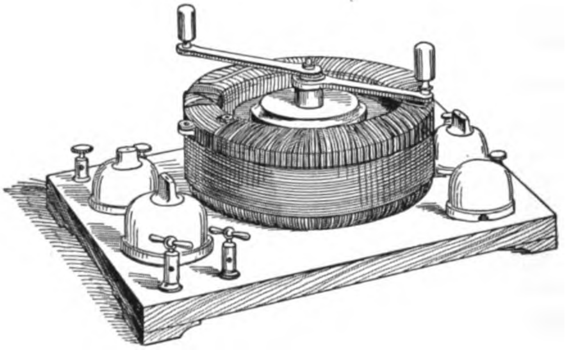

Fig. 125.—Cautery transformer.

Fig. 125 shows the form in which a transformer is often used for cautery purposes. It consists of two separate coils of insulated wire, one of which fits inside the other, but the number of its turns traversed by the primary current may be reduced if it is desired to reduce the strength of the secondary current. The inner coil contains an iron core. It is a *step-down transformer*, since it gives a secondary current of lower voltage than the primary current. The primary coil, therefore, has a large and the secondary a small number of turns. Its special usefulness for the cautery lies not in the diminished voltage, but in the increased amperage. A platinum wire No. 26, B. & S. gauge, will become incandescent or even white hot from the passage of a current of 4 volts and 10 amperes, and make an excellent cautery. The same energy as a current of 110 volts and 0.4 ampere would not heat the wire perceptibly. A current of 110 volts and 10 amperes would produce the same heating effect upon the platinum wire, and this could be obtained from the electric-light circuit, but there are two important reasons why it is better to use a step-down transformer:

one is that it would be dangerous to take a current as strong as 10 amperes from one of the 110 volts electric-light sockets; there would have to be special wiring of the house and fused knife-switches at the outlet to prevent damage from fire, just as in the case of the heavy currents used for the *x*-ray. When we remember that for some purposes a cautery current of 50 or even 80 amperes is used, the employment of the 110-volts current is seen to be out of the question. The transformer enables us to use a current of only 0.5 ampere and 110 volts, and convert it into a cautery current of 10 amperes or more. It is, therefore, practicable to attach it to any ordinary alternating current light socket. The second reason why the transformer is regarded as necessary to fit the alternating electric-light current for cautery use is the danger and discomfort to operator and patient from handling and applying an uninsulated wire charged with an alternating current of 110 volts.

The Production of the Secondary Current in an Alternating Current Transformer.—Each time the primary current begins to flow in a direction which we will call *A*, a current is induced in the secondary coil and in an opposite direction to that in the primary. When the current ceases to flow in the direction *A* in the primary, a current in the same direction is induced in the secondary coil. These are exactly analogous to the make and break currents in an induction coil. In the case of the alternating current there is another element. At the instant that the primary current ceases in the direction *A*, it begins in the direction *B*, and this induces a make current in the secondary coil in a direction contrary to *B*, or, in other words, in the direction *A*. At this instant two forces tend to produce currents in the secondary coil and both of them in the direction *A*. The two forces are the secondary electromotive forces due to the break of the primary current, *A*, and the make of the primary current, *B*. The result is the induction of a powerful secondary current in the direction *A*. At another part of the cycle the make of the primary current *A* and the break of the primary current *B* are simultaneously operative in producing a secondary current in the direction *B*. The alternating currents, *A* and *B*, in the primary coil join forces in the production of an alternating secondary current. The secondary current may be of the same character as the primary current, and present a series of currents of full strength, first in one direction and then in the other, with such a sharp transition between the two as practically to cause a break in the current. Or the amount of self-induction in the primary and secondary coils and perhaps in an inductance coil introduced in the primary circuit for this purpose may be so regulated as to produce a current analogous to the sinusoidal current. A chart of the secondary current might then present a continuous curve extending alternately above and below the neutral line, and undergoing much less abrupt transitions than those seen in a chart of the alternating electric-light current. Such a sinusoidal current, adjustable at from 5 to 30 volts, is of value in therapeutics, except in cases where a unidirectional current is required, as for diagnosis or for electrolysis.

This type of step-down transformer has greater efficiency than if the two coils were straight and open at the ends, this fact being due to the energy wasted at the two open ends of each coil, just as the greatest efficiency in an electromagnet is not obtained in a straight bar. The magnetic flux in the latter case is carried partly by the iron and partly by the air, through which it effects a return to the first end of the iron bar. The quantity of magnetic flux and the weight-bearing attraction of the magnet are not so great with this as with the complete ferric type of magnet, of which the horseshoe magnet, with its iron armature, forms the most familiar example. In the same way a transformer of the straight cylinder type wastes a certain number of expanding and contracting lines of force and is less efficient than the closed magnetic ring type of transformer. The straight type is simple in construction, and the strength of the current may be readily regulated by moving one of the coils out of or further into the other, and for most electrotherapeutic work the advantages offset the fact that it takes a little more primary current than some other types to yield the same secondary current.

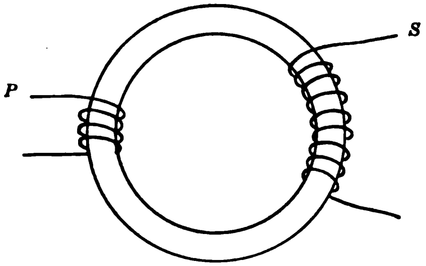

Fig. 126.—Diagram of a step-up transformer: *P*, Primary; *S*, secondary.

A *step-up transformer* may present the same appearance as a step-down transformer, but it has a greater number of turns in the secondary than in the primary coil. The voltage of the secondary current is proportionately greater, and may even be great enough to excite an *x*-ray tube or a high-frequency apparatus. These are, in fact, the principal purposes for which a step-up transformer for the alternating electric-light current is used in therapeutics. In both of these cases the maximum efficiency is desired and a closed magnetic ring transformer is generally used. Fig. 126 shows in a diagrammatic way the construction of a transformer of this type. It consists of a complete ring of soft iron and two coils of insulated wire passing around the iron at the same or different parts of its periphery. One of these wires transmits the 110 or 220 volts alternating electric-light current, and is called the primary. The other wire has alternating currents induced in it by the action of the primary current, and is called the secondary. The ends of the latter are attached to the poles of an *x*-ray tube or to any other apparatus through which it is desired to send an electric current. The voltage of the secondary current bears the same ratio to that of the primary current that the number of turns in the secondary bears to the number of turns in the primary coil. This type of transformer may, therefore, be used as a step-up or a step-down, according to whether the primary current is connected with the coil having the smaller or the larger number of turns. In either case the efficiency of such a transformer is very great, about 97 per cent. of the energy required to produce the primary current reappearing as energy in the secondary current. The energy required to send the exciting current through the primary coil consists of two factors. The first is that which is required to overcome the ohmic or frictional resistance in the primary coil. This would be almost the total energy required if there were only a primary coil. This is lost as electric energy and reappears as heat. The second is the energy required to induce the current in the secondary coil. The secondary current performs work in whatever apparatus, cautery, or *x*-ray tube, for example, it is supplied to, and energy is assuredly required to produce it. An illustration from mechanics may make this clear. A man may have to exert only a small amount of energy to turn a crank and cause a cog-wheel to revolve if only frictional resistance is to be overcome; but if the cog-wheel is connected with a pulley by which a heavy weight is to be lifted, the man must exert just so much additional energy in order to make the cog-wheel revolve. The additional resistance to the revolution of the cog-wheel which the man must overcome is the force exerted by the heavy body tending to cause the cog-wheel to revolve in just the opposite direction. Returning now to the transformer, the secondary current actually does exert a force tending to produce a current in the primary coil, which would be in the opposite direction from the primary current. This opposing force to be overcome in the primary coil is called counterelectromotive force.

The actual ring shape is not essential to the closed magnetic ring transformer. It is often better to have it made up of many separate narrow iron plates riveted together so as to form a hollow rectangle. This is very easily constructed and the winding of the two coils of wire about the iron core is greatly simplified. In fact, the coils are wound separately and then the proper section of the core slipped inside of them before being riveted to the other sections. In some cases the primary and secondary coils are wound about different parts of the circumference of the magnetic ring, and in other cases one is wound directly over the other, as in the case of an induction coil. The same precaution as to insulation must be taken as with an induction coil of equal voltage. Very high-tension transformers are usually immersed in oil, which has been found a convenient and highly effective insulating medium. This is, of course, in addition to the insulated wrapping placed around the fine wire before it is made up into a coil.

The current from a step-up transformer is of an alternating character and differs from that from an induction coil in being equal in both directions. It is wonderfully well adapted to x-ray purposes, provided one set of impulses is suppressed, or if the currents are rectified by a commutator. This requires special appliances which are not necessary in the case of an induction coil. In the latter the make or inverse discharge is so much weaker than the direct or break discharge that very often no special apparatus has to be employed to suppress it. And when it is troublesome, very simple regulation of the conditions will often prevent it. Thus, the introduction of a spark-gap at one or both poles of the x-ray coil will usually stop the inverse discharge because of the relative weakness of the latter as compared with the direct discharge which will pass across the spark-gaps unimpeded. Another simple means which is often effective in the case of an induction coil is the regulation of the self-induction in the primary coil by varying the number of turns through which the current is sent. Varying the different connections of the x-ray tube itself, an anticathode and accessory anode and vacuum regulator will often accomplish the result. These various measures prove ineffective in the case of a step-up transformer for the reason that the currents are similar and equal in both directions, and these various procedures would have about as much effect upon the currents flowing in the desired direction as upon those in the opposite direction. The alternating current transformer without any modification has been used to actuate an x-ray tube, and was thought fairly satisfactory until the induction coil was brought to its present state of efficiency. The recent work of d'Arsonval and Gaiffe has resulted in the application of devices for suppressing one set of impulses from the transformer. Snook and others rectify the secondary current. These two devices result in the production of a current so uniform, efficient, and so easily regulated that the modified transformer is probably the best *x*-ray apparatus in existence. It requires no interrupter. It works upon the alternating electric-light current, and has such advantages over the induction coil as to render it desirable even where the supply current is of the direct type. In the latter case a motor generator or a rotary transformer operated by the direct current is employed to produce the alternating current for the transformer. This adds somewhat to the cost, but very little to the care of the apparatus. The most essential points in the suppression of one set of impulses is the presence of two ventril or valve-tubes connected in series and forming a shunt circuit between the two poles of the coil. Each ventril tube is a vacuum tube with electrodes of two different characters, one of which will readily act as a cathode and the other will not ordinarily do so. Secondary currents can pass through such a ventril tube without hindrance in a certain direction, but with the greatest difficulty in the opposite direction. Introducing one or, as in Gaiffe's apparatus, two ventril tubes between the poles of a transformer has the effect of affording a short and direct path for the secondary currents in one direction while having no effect upon those in the other direction. The two poles of the transformer, therefore, transmit to the *x*-ray tube a uniformly interrupted series of secondary currents which are all in one direction. Fig. 127 shows the general arrangement of these ventril tubes; *p* and *p'* are the two poles of the transformer and the two ventril tubes are arranged so that the currents enter the corresponding end of each tube, the positive end of one tube being connected to the negative end of the other by a conducting wire; *p'*, which is marked +, is the pole which is to be connected with the anode or positive terminal of the *x*-ray tube; and *p*, which is marked −, is to be connected with the cathode of the *x*-ray tube. Negative impulses from *p'* pass readily through the ventril tubes whose cathodes are both nearest *p'*, but negative impulses from *p* find a tremendous resistance to their passage through the two valve-tubes. Just a word as to the construction of a ventril tube may not be out of place. It

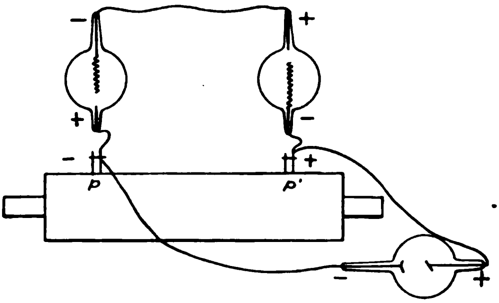

Fig. 127.—General arrangement of ventril tubes.

is a tube of about the same degree of vacuum as an x-ray tube, and should be provided with a means of regulating the vacuum. The type shown in the illustration has two leading-in wires, one of which terminates in a small aluminum electrode, and the other in a long spiral of aluminum presenting many times the surface area of the first. The high-tension current used for x-ray work encounters very little resistance when passing in such a direction that the cathode is the electrode with very large area, but is arrested when the polarity is reversed. The negative current will pass from the long spiral electrode to the small one, but it will not pass in the opposite direction. A different use has sometimes been made of a ventril tube, placing it in series with the x-ray tube, so that it will allow the current to pass through it to the x-ray tube in the proper direction, but will act as an insuperable resistance to currents in the opposite direction. The ventril tube is thus used as a valve to permit the passage of the direct discharge from an induction coil through the x-ray tube and to obstruct the inverse discharge. So that we use the current which the ventril tube transmits readily. In Gaiffe's apparatus the ventril tubes are used to shunt or side-track the currents, which they will readily transmit, and to leave a unidirectional discharge to pass immediately from the poles of the transformer to the x-ray tube. This is probably the best arrangement. Other valve-tubes are described on p. 749. Gaiffe's apparatus for the employment of an alternating current transformed for x-ray work includes liquid volt controllers, condensers, and other appliances which will be described on another page. The whole combination is a practicable thing, whereas a simple transformer is not perfectly adapted to the purpose. Snook's and similar transformers with a rectifying high-tension discharge are further discussed on p. 721.

DETECTION AND MEASUREMENT OF VOLTAIC CURRENTS

Dynamic electricity produces measurable physiologic, chemic, mechanic, and physical effects. Under the latter head would be included thermal, luminous, and magnetic effects. The magnetic effects are especially available for ascertaining the presence and strength of voltaic currents, and will be the first to be described.

ELECTROMAGNETIC GALVANOMETERS

Oersted's initial discovery in regard to the intrinsic relation between electricity and magnetism consisted in the observation that if a current of electricity passes through a wire passing above or below a magnetic needle like a compass, the needle tends to place itself at a right angle to the plane of the wire. As to direction, if the current is above the needle and is passing from south to north, the north pole of the needle

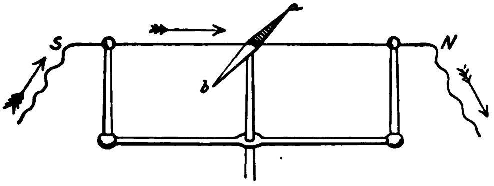

Fig. 128.—Principle of the compass galvanometer.

will be deflected toward the west; if the current is from south to north and is below the needle, the latter is deflected toward the east; just the opposite deflections occur if the current is flowing from north to south (Fig. 128).

Fig. 129 represents the case of a galvanometer with a single needle *a-b*, and a current flowing through a single complete turn of wire. The current passes from south to north above the needle and returns from north to south below the needle. Both parts of the loop, therefore, carry a current which tends to make the needle swerve to the west. The angular distance through which the needle moves depends principally upon the strength of its magnetism (which tends to keep it in a north and south direction) and upon the strength of the current. Using the same needle for different observations, the apparatus will serve as a measure of the strength of the current. The strength of the effect upon the needle is multiplied by using a coil of many turns of wire instead of a single loop; and the sensitiveness of the needle is increased by making it astatic. This, Fig. 130, consists of using two magnetic needles fastened to the same vertical axis, one with its north pole pointing in the usual direction, but the other with its poles reversed. Both are suspended by a silk thread and the coils of wire pass around only the lower needle. The effect is the same as it would be upon a needle of the size of both combined, and with the magnetism of both combined, but opposed by the influence of the earth's magnetism only to the extent represented by the difference between the strength of the two needles. These must not be exactly equal. If they were there would be no force opposed to the directive influence of the electric current, and weak as well as strong currents would cause the needle to assume a position at right angles to the plane of the wire. This would destroy its value as a means of measuring the strength of different currents.

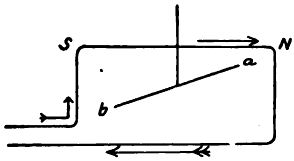

Fig. 129.—Ordinary magnetic needle.

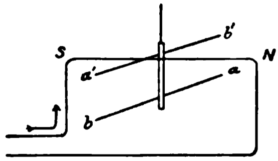

Fig. 130.—Astatic magnetic needle.

The strength of the current is indicated by the degree of the angle of deflection. It is difficult to calculate this from purely theoretic data, and these instruments are usually graduated by passing currents of known strength through them and marking the angles reached by the needle upon the dial of the instrument. In doing this the instrument which is to be graduated and a standard galvanometer which is known to be accurate are connected in series, the current passing through first one and then the other in completing its circuit from the positive pole of the battery back to the negative pole. It is an established fact that the strength of the current is the same at every point of a single continuous circuit. Therefore the current strength indicated by the standard galvanometer is the same as that passing through the galvanometer which is being tested. The point to which the needle of the latter is deflected is therefore marked as indicating that particular strength of current. Different strengths of current are obtained for the purposes of this test by using batteries of different strengths or by a rheostat, or resistance regulator, or by a shunt volt regulator for reducing the electric-light current to different suitable strengths.

The resistance of a galvanometer without its shunt is usually from 100 to 600 ohms.

The **d'Arsonval milliamperemeter** and several other types of electromagnetic galvanometer in common use are described on pages 180–185.

Hot Wire Galvanometer.—This depends upon the heating effect of an electric current upon a fine wire through which it passes with considerable ohmic resistance. The hot wire expands and allows the pointer to move across the dial under the influence of a spring. It is applicable to alternating and high-frequency currents, as well as direct currents, and to almost any voltage. It is difficult to secure great accuracy with an instrument of this type.

Amount of Heat Produced by an Electric Current.—The amount of heat, as shown by the formula $2H = C^2R$, is proportional to the resistance multiplied by the square of the current. With the same number of voltaic cells in series, and consequently a certain uniform voltage, the current varies inversely as the resistance $(C = \frac{V}{R})$, and in therapeutic applications the resistance is greatest with a small area of contact between the electrode and the body. A sponge electrode with a surface of 4 square inches may, for example, be applied to the nape of the neck, and the other electrode consist of a silver probe making a contact with the mucous membrane of the gum over an area of perhaps only $\frac{1}{50}$ square inch. The same current is passing at both places, and the amount of heat produced at each electrode is proportional to the resistance at that place of contact. There would be no perceptible warmth at the sponge electrode with a current of 1 or 2 milliamperes, while at the electrode applied to the gums, where there is a great many times more resistance, the heat would be very disagreeable.

The factor of heat at the contact surfaces between the body and the electrodes probably has something to do with the reduction in resistance which occurs after a short period of flow of the continuous current. This lessened resistance takes place when the electrodes are applied to a wet thread or to a nerve which is apparently homogeneous. It can be demonstrated by the Wheatstone bridge.

The production of a large amount of heat by electricity involves two factors: the flow of a heavy current through great resistance. A marked rise in temperature is obtained when a large amount of heat is generated in a small portion of matter. The human body is not especially favorable as an object in which to develop a high temperature by electric currents. The resistance of the body is so great that the strength of the current transmitted is very small indeed in comparison with metallic conductors. And the small amount of heat which is generated is quickly removed from the point of contact, partly by the circulation of the blood and lymph and partly by ordinary conduction.

The fact that a boy's arm and leg may have to be amputated in consequence of circulatory disturbances from contact with a wire carrying 6600 volts and without any burn is very striking.

The *galvanocautery* applied for surgical operation is an entirely different matter. The heat is not produced by the passage of an electric current through the patient's body, but through a metal wire or strip which has a resistance which though considerable allows the passage of a very heavy current. The resistance is a great deal less and the current a great deal stronger than is ever the case with the human body. The large amount of heat which is generated is produced in a very small mass of metal, which is accordingly raised to a red or white heat. It is the hot metal which cauterizes the flesh, not the electric current.

Regaud's Electric Thermostat.—This is an example of the practical employment of the heat-generating property of the electric current. It consists of an hermetically sealed glass tube of a U shape, partly filled with mercury. The upper part of the left limb contains rarefied hydrogen gas, which by its pressure maintains the mercury at a certain level, leaving a vacuum at the top of the other limb. A leading-in wire from one electric-light wire reaches the level of the mercury in this tube, and the current is transmitted through the mercury to the other leading-in wire, through the heater *h*, and thus to the other electric-light wire. The whole apparatus is placed inside the bacterial culture chamber, or whatever space is to be heated to a uniform temperature. If the temperature rises beyond a certain point, the hydrogen gas expands and depresses the level of the mercury in that arm of the tube to such an extent as to break the contact with the leading-in wire and cut off the electric current. The thermostat may be adjusted for any desired temperature by adding mercury stored in a little side tube to that in the main tube, or by pouring some out of the main tube into the side tube. A still finer adjustment is made by inclining the tube and reducing the mercurial pressure by lessening the difference in level between the mercury in the two arms of the tube.

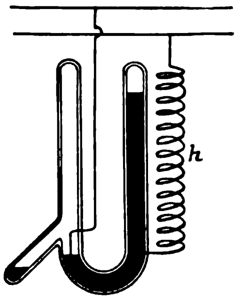

Fig. 131.—Regaud's electric thermostat.

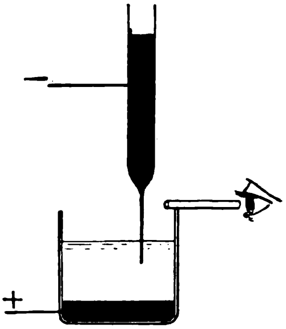

Fig. 132.—Lipmann's capillary electrometer.

The Capillary Electrometer.—This is an instrument which is useful in measuring the electromotive force or potential differences producing physiologic or pathologic electric currents in animals or plants. It is very sensitive, though not so sensitive as a galvanometer may be made. It has the advantage of giving accurate measurements of the electromotive force, even of a voltaic couple of extremely great internal resistance. This is the condition in physiologic and pathologic currents, and is not so perfectly met by a galvanometer. The capillary electrometer acts under these conditions of small electromotive force and very great internal resistance practically in an electrostatic manner.

Lipmann's capillary electrometer (Fig. 132) is based upon the influence of electricity upon surface tension and capillary attraction. A glass tube, the lower part of which is of capillary caliber and dips into a jar of dilute acid, is open top and bottom and has its upper part filled with mercury. Under these circumstances the mercury does not run out of the tube, but rests at a certain level upon the surface of the dilute acid in the capillary portion of the tube. As usually constructed, this level is above the general level of the solution in the jar. The level may be adjusted by changing the pressure of the column of mercury. Observations of the level are made with a microscope or an image of the capillary electrometer may be thrown upon a revolving cylinder of photographic paper and produce a record of the variations. Connecting the mercury in the upper part of the tube with the negative wire and the mercury in the bottom of the large jar with the positive wire, the level of the surface at which the mercury and the acid solution meet in the capillary tube rises the moment the current is turned on. The difference in potential between the two masses of mercury is proportional to the height to which the level rises or also to the mercurial pressure required to maintain the original level. This form of electrometer is extremely sensitive, responding to even the weak currents characteristic of animal electricity, and is instantaneous in its response to such currents and in its return to the zero mark after the current ceases. It is used in many physiologic experiments, such as the measurement of muscular currents.

The String Electrometer.—Einthoven's string electrometer is based upon the fact that when a current of electricity passes through a wire tightly stretched in a powerful magnetic field the wire is deflected toward one of the poles of the magnet. A powerful light and a high-powered photomicrographic apparatus are used to throw an image magnified 250 times or more upon a moving strip of bromide of silver photographic paper through a slit which is at right angles with the length of the wire. The string or wire originally used by Einthoven consisted of a filament of quartz obtained by directing the flame of a blow-pipe upon a piece of quartz fastened at one end and having a heavy weight suspended from the other. The silvered quartz thread was one-third the diameter of a red blood-cell. The electric resistance was about 10,000 ohms. The apparatus improved by Nicolai and Huth (page 319) employs a platinum wire about 4 inches long and having a resistance of 6000 ohms. In either case the electromagnet must be a powerful one and in Nicolai's apparatus weighs 60 pounds. It must be actuated by a direct current, either from the electric-light circuit or from a storage battery.

Correction for Internal Resistance in Measuring the Electromotive Force of a Voltaic or a Storage-cell during Discharge.—It is not sufficient to determine the difference in potential between the two poles of the battery by means of a voltmeter or a potentiometer. The number of volts found in this way while a current is passing through the battery must be corrected by taking into account the fact that the resistance of the electrolyte in the battery cell through which a current is passing will in itself require a difference in potential equal to the current multiplied by the internal resistance. This amount in volts is to be added to the measured difference in potential between the two poles to find the total electromotive force of the cell.

Thus, with a storage-cell the voltmeter or the potentiometer may show a difference in potential of 1.6 volts between the two poles, with a current of 2 amperes through an external circuit, as measured by a galvanometer. We know that the current through the battery is also of the same strength—2 amperes. If the internal resistance of the cell is measured and found to be 0.2 ohm, then, according to our rule, $\overset{\text{ohm}}{0.2} \times \overset{\text{amperes}}{2} = \overset{\text{volt}}{0.4}$ must be added to 1.6 volts, measured difference in potential between the two poles. This makes a total electromotive force of 2 volts.

Another condition remains to be considered. In the case of a battery with a certain number of volts difference in potential between its poles the current passing through the external circuit is equal to the voltage at the two poles, divided by the resistance in the external circuit. But doubling the external resistance does not cause the current to be just half as great. In order to reduce the current one-half, the total resistance, internal as well as external, must be doubled. The difference in potential at the two poles will be found to have undergone a change if only the external resistance is varied, and the new strength of current cannot, therefore, be calculated from the old voltage at the two poles. The new voltage may be measured by a voltmeter or a potentiometer, and then this may be divided by the new resistance of the external circuit to obtain the number of amperes of current.

The total electromotive force divided by the total resistance always gives the strength of the current; and whatever the intermediate voltages or resistances may be, their effect is determined only by combination with the conditions in the remainder of the circuit.

The current from a single storage-cell with an external resistance of $\frac{1}{1000}$ ohm may be 10 amperes. And this would indicate two different things. One is that under the conditions described the potential difference between the poles of the battery is only $\frac{1}{100}$ volt ($V = CR$ or $\frac{1}{100}$ volt $= 10$ amperes $\times \frac{1}{1000}$ ohm, according to Ohm's law). This is true in spite of the fact that on open circuit or with a large external resistance the potential difference between the two poles of the cell will be 2 volts or over. The other fact, which is indicated when the current produced by a known electromotive force of about 2½ volts and an external resistance of only $\frac{1}{1000}$ ohm is only 10 amperes, is that the current strength must in this case be almost entirely determined by the internal resistance of the storage-cell. If it depended only on the $\frac{1}{1000}$ ohm external resistance, an electromotive force of 2½ volts would produce a current of 2500 amperes. This will be found to be of importance in studying electric currents produced by physiologic processes. The difference in potential between two portions of the body may be 0.08 volt, but if these are joined by a conductor of 1 ohm resistance, the current will not be $\frac{0.08 \text{ volt}}{1 \text{ ohm}} = 0.080$ ampere, or 80 milliamperes, but a very much weaker one. The resistance of the body may be 1000 ohms or more, and this must be added to the external resistance in calculating the strength of the current. The total electromotive force may in this way be approximately the 0.08 volt difference in potential on open circuit.

The Measurement of the Potential at a Single Electrode.—This finds its most evident application in the case of *static electricity*, where the potential is so high that the divergence of a gold-leaf electroscope forms the basis of measurement.

The potential generated by physiologic processes is so small that much more sensitive instruments are required to measure it. The most practicable plan is to lead an insulated wire from the single source of potential which it is desired to measure and have this wire terminate in an electrode which is non-polarizable in a certain electrolyte. A standard electrode whose potential is known is placed in another part of the same electrolyte. The difference between the potentials of the two electrodes is found by means of the potentiometer, and from this the unknown potential is readily calculated.

Fig. 133 shows a practicable arrangement of the two electrodes, the calomel electrode being used as a standard. This electrode consists of mercury covered by a layer of calomel, and the wire dipping into it is insulated from contact with the electrolyte (normal KCl solution) by a glass tube. Inverted U-shaped tubes from this jar and from the jar containing the other electrode dip into the same solution in a middle jar. These inverted U-shaped tubes are filled with the same solution by blowing through the rubber tubes shown in the diagram. There is thus a continuous liquid path between the electrodes, protected against the effect of vibration and forming really a voltaic cell on open circuit. The calomel electrode has a potential of +0.5600 volt; it is positive and the liquid negative. As an example, the difference in potential between the two electrodes might be 0.6300 volt, the calomel electrode being positive. This would show that the unknown potential was +0.5600 − 0.6300 = −0.0700 volt.

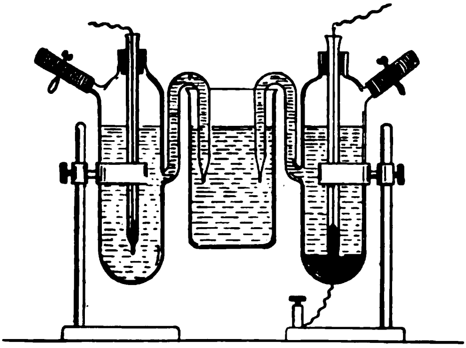

Fig. 133.—Calomel electrode used to measure the potential at a single electrode.

Known Potential of Calomel Electrode − Difference in Potential = Unknown Potential. Hence,

Potential of Calomel Electrode.		Difference in Potential.		Unknown Potential.
+0.5600	−	0.6300	=	−0.0700

Another example would be:

Potential of Calomel Electrode.		Difference in Potential.		Unknown Potential.
+0.5600	−	0.5000	=	+0.0600

Errors arising from chemic action between the standard electrode and the electrolyte may be guarded against by measuring the difference in potential before connecting the standard electrode with the unknown source of potential. The difference so found may be regarded as the potential of the calomel electrode in the different calculations.

The Hydrogen Electrode.—This is another standard electrode giving a very definite potential and used for measuring the potential of a single electrode. It consists essentially of a platinized platinum plate half immersed in a suitable electrolyte and half surrounded by hydrogen gas which bubbles up through the electrolyte. The potential of the hydrogen electrode in normal sulphuric acid solution is +0.277. This is less convenient to use and more liable to error than the calomel electrode which is correct down to $\frac{1}{10}$ millivolt or $\frac{1}{10,000}$ volt.

The Telephone.—The telephone, in addition to its wonderful commercial value, is useful as a diagnostic means in detecting the presence of electric currents and in testing the acuteness of hearing, and has some value as a therapeutic agent in the application of sound in ear and brain diseases.

The apparatus consists essentially of a transmitter and a receiver, and there may be an electric battery. The transmitter is used by the speaker in an ordinary long-distance conversation. Words spoken into it produce characteristic vibrations in an iron diaphragm, which is made to move toward and away from the end of a magnet. As the armature approaches the magnet the attraction between the two increases and the strength of that magnetic pole is increased. The magnet is surrounded by an induction coil in which a current is generated by the expanding lines of force produced by the increase in strength of that magnetic pole. The wire of this coil is continuous with the two wires leading to and from the distant receiver, and with the induction coil of the latter. The induced current travels through the entire length of this wire at the rate of 188,000 miles a second, and is, therefore, almost instantaneously sent through the other part of the wire, forming the induction coil of the receiver. There it acts to strengthen that magnetic pole, and, therefore, to attract an iron diaphragm. The diaphragm of the transmitter moves away from the magnet at the other part of each vibration, and causes a diminution of strength in that pole of the magnet. This induces a current in the opposite direction from that first described, and the effect of this at the receiver is to diminish the attraction exerted upon the iron diaphragm. The millions of vibrations produced by the sound of the human voice at the transmitter are accurately duplicated by the diaphragm of the receiver. The vibrations of the latter are communicated to the air and cause sounds which are an almost perfect reproduction of the human voice. An electric battery is very commonly used now. It sends a continuous current through the coils in the transmitter and receiver and through the conducting wire as soon as the telephone is taken from its hook to be used. The magnets are electromagnets of soft iron, magnetized by the current, and the effect of the vibrations of the iron diaphragm in the transmitter is to produce variations in the strength of the current. These variations are repeated in the coil of the receiver, and produce variations in the strength of the magnet, with corresponding vibrations of the diaphragm. This is found to be more effective than depending on permanent magnets in the transmitter and receiver without any battery.

The **use of the telephone** as a delicate test for the presence of electric currents makes it valuable in measurements of resistance and of electromotive force. This is illustrated on p. 173.

The Telephonic Bullet Probe.—Dr. John H. Girdner, of New York, was probably the first to publish a description of such an instrument. A telephone receiver has one of its wires connected with a metal bullet probe which may, but need not necessarily, be insulated except at its tip. The latter is of metal. The other wire goes to one pole of a battery of two or three voltaic cells or to one pole of a small induction or faradic coil, the other pole of which may be held in the patient's hand. The electric contact is decidedly better or the resistance less when the probe touches a piece of metal, such as a bullet embedded in the flesh, and a sharp click heard in the telephone receiver announces the fact.

As a Test for Hearing.—Urbantschitsch has devised the apparatus shown in Fig. 134. This consists of a telephone receiver, which the patient holds to his ear, a secondary coil, with which the telephone is connected and which is placed inside of two separate primary coils. The latter are exactly similar and are supplied with the same current from a battery or from the electric-lighting circuit, the interruptions being made inside a sound-proof box. When the two primary coils are in exactly the right position, the effect of one upon the secondary coil exactly counterbalances the effect of the other, and there is a complete absence of sound in the telephone. One of the primary coils is

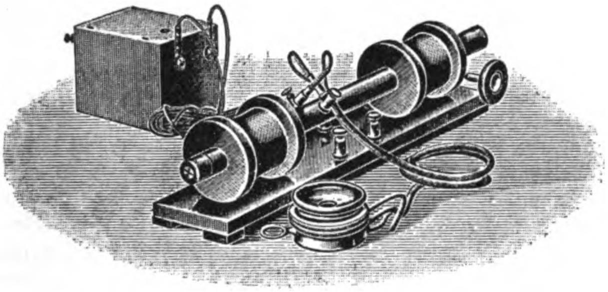

Fig. 134.—Urbantschitsch's telephone apparatus for testing hearing.

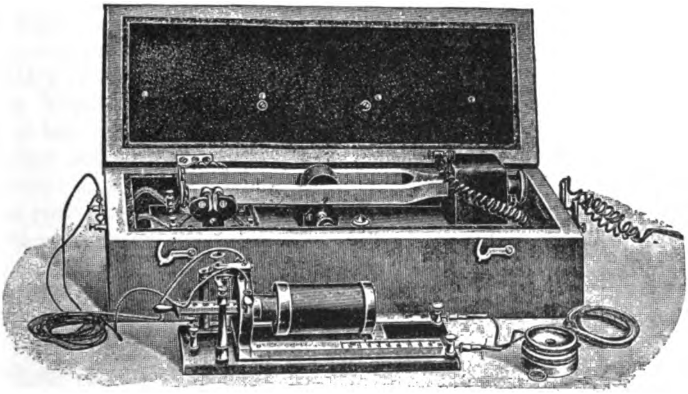

Fig. 135.—Breitung's telephone apparatus for testing hearing.

fixed, but the other is movable by a rack and pinion. Moving this coil toward the center of the secondary coil causes more and more secondary current to be induced, and more and more noise to be produced in the telephone. The point at which the patient is able to hear the sound furnishes a mathematic value for record or comparison.

It is possible to use a single primary and a single secondary coil in the same way, but they would have to be separated to an inconvenient distance in order to secure complete absence of sound. With the two primary coils only two or three inches of motion are required to change from the maximum sound to complete silence.

Fig. 135 shows Breitung's apparatus for the same purpose. There is a large tuning-fork set in vibration by an electromagnet and inclosed in a sound-proof box. The telephone is excited by the secondary currents in an induction coil, the primary wires of which are not connected with any battery, but with electromagnet coils placed near the vibrating ends of the tuning-fork. The back and forth motions of the steel tuning-fork generate alternating currents in the primary coil. The loudness of the sound in the telephone is varied by moving the secondary coil nearer to or further from the primary. The advantage of this over the other instrument is in the fact that a pure tone is produced or sound consisting altogether of one wave length.

Cases of deafness are sometimes benefitted by the application of sound vibrations by means of such apparatus as the telephone or the phonograph. This may be called a very mild form of *auditory massage.*

The Potentiometer.—This is an arrangement of apparatus for measuring the difference in potential between any two points, such as the poles of a battery, and acts equally well whether the battery is on open or closed circuit.

It consists of resistances, a standard cell, and a galvanometer, and its principle is the balancing of the electromotive force of the one against that of the other in such a way that no current flows through the galvanometer.

Fig. 136 shows the arrangement diagrammatically.

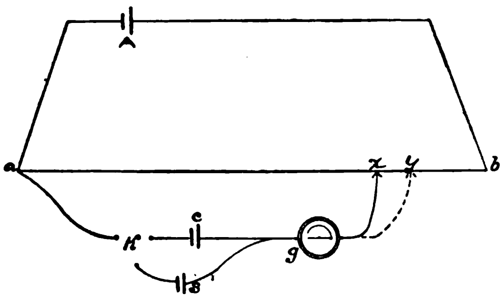

Fig. 136.—The potentiometer.

The wire *a–b* has a uniform thickness and considerable resistance, and the resistance of any two portions of it is proportional to their length measured upon a metal scale over which it is stretched. At its two ends this wire is connected by a wire of very small resistance with a constant battery, such as a single storage-cell *A*. The difference in potential between the two ends of this wire will be about 2 volts. *c* is the cell which is to be tested, and it must have an electromotive force less than that of the battery A. The positive pole of c is connected to a, the positive end of the resistance wire; and the negative pole, after first passing through the galvanometer g, makes a slide contact with the resistance wire at the point x. The circuit $a\,c\,g\,x$ is in shunt to the circuit $a\,x$, and if it were not for the electromotive force of the cell c, a current would flow through $a\,c\,g\,x$ in consequence of a certain fraction of the electromotive force of the storage-cell A. The difference in potential between a and x varies with the resistance between the two and is regulated by moving the sliding contact. The electromotive force represented by the difference in potential between a and x, and tending to produce a current through $a\,c\,g\,x$ is opposed by the electromotive force of the cell c, which tends to produce a current in the opposite direction through $x\,g\,c\,a$. The sliding contact is adjusted until the galvanometer shows that no current is passing through the circuit $a\,c\,g\,x$. A standard cell with a known electromotive force, such as the Clark or the cadmium cell, is then substituted at s for the unknown cell c by turning the contact key k. A point y is then found, by the sliding contact, where no current passes through the galvanometer. The difference in potential between a and x is equal to the electromotive force of the cell c; and that between a and y to the electromotive force of standard cell s. These two are proportional to the resistance $a\,x$ and $a\,y$. Therefore,

$$\frac{\text{Electromotive force of } c}{\text{Electromotive force of } s} = \frac{\text{Resistance } a\,x}{\text{Resistance } a\,y}.$$

In the case of the single straight wire in the diagram the lengths $a\,x$ and $a\,y$ may be measured and substituted for the resistances $a\,x$ and $a\,y$ in the above equation.

A resistance box with resistance coils giving any required resistance can be used in the same way, and is much better than the simple straight resistance wire. The latter was used in the illustration simply because of its diagrammatic simplicity.

The measuring instrument may be a d'Arsonval galvanometer or a capillary electrometer.

The Electric Conductivity of Liquids.—The *conductivity* of a liquid is the number of amperes of current which a cube of the liquid measuring one centimeter on each side will transmit under a pressure of one volt.

The *current density* is the number of amperes per square centimeter of cross-section in the path of the current. *Potential gradient* is the fall in potential (in volts) per centimeter of the length of the conducting path.

The *conductivity* of a liquid may be described as the current density under unit potential gradient.

The *specific resistance* is the *reciprocal of the conductivity*, and is expressed in ohms.

The conductivity of sulphuric acid at its strength of maximum conductivity and at a temperature of 18° C. is 0.7398. Its specific resistance is $\frac{1}{0.7398}$ ohm, or 1.353 ohms. This is the resistance of a cube of this liquid one centimeter on a side.

The *specific resistance* of a liquid is the number of ohms of resistance offered by a cube of this particular liquid one centimeter on a side. It is found by dividing the number of volts difference in potential per centimeter of distance between the electrodes by the number of amperes per square centimeter of opposed surfaces of the electrodes.

The *resistance* offered by any body of liquid through which the current passes is expressed in ohms. The *conductance* of the same body of liquid is the reciprocal of the number of ohms, or 1 divided by the number of ohms.

Mho is a word coined by spelling *ohm* backward, and is used in giving a numeric value to the conductance of a body of liquid or of any other conductor. The conductance expressed as so many mhos is the same as 1 divided by the number of ohms resistance.

The conductance of a trough of liquid into which two electrodes dip may be found by calculation if we know the conductivity of the liquid, the surface area of the electrodes, and their distance apart. Take the case of the sulphuric acid solution referred to above. Its conductivity is 0.7398, and say that the electrodes are plates 10 centimeters square (*i. e.*, each has an area of 100 square centimeters), facing each other at a distance of 5 centimeters. The conductance will be found by multiplying the conductivity 0.7398 by 100, the area of cross-section of the conducting path, and dividing by 5, the length of the conducting path:

$$\text{Conductance} = \frac{0.7398 \times 100}{5} = 14.796 \text{ mhos.}$$

The resistance of such a trough of dilute acid would, of course, be $\frac{1}{14.796} = 0.0696$ ohm.

Liquid Resistances.—These may be introduced into a circuit to reduce the strength of the current; and if the area of the two electrodes or the distance between them is adjustable, a liquid resistance may be used to regulate the strength of the current.

The name *liquid volt-controller* is properly applicable only when such a cell is shunt to the circuit of utilization.

An adjustable liquid resistance is used as a rheostat or as a volt-controller in several different types of *x*-ray apparatus to regulate either the primary or the secondary current. Gaiffe's transformer for *x*-ray and high-frequency currents, one of the most modern types of apparatus, uses liquid resistances in the secondary circuit.

The resistance of a liquid varies very greatly with its temperature, with its concentration, and with its exact chemic composition. Some few liquids have a conductivity and a temperature coefficient which make them suitable for the gross regulation of the current. The resistance of aqueous solutions varies about 2 per cent. for each degree Centigrade.

Liquid resistances are never constant, so as to make them suitable for use in the exact measurement of electric currents. They cannot take the place of coils of wire for this purpose.

Polarization in Liquid Resistances.—The flow of the current is almost entirely dependent upon electrolysis. The purest water obtainable, redistilled and preserved from contact with the air in glass vessels of as little solubility as possible, for glass itself varies in solubility, is with difficulty electrolyzed, and has a conductivity of only 0.04×10^{-6}, or 0.00000004. On exposure to the air the conductivity of distilled water rises to 0.07×10^{-6}, and water is not considered satisfactory for conductivity if its own conductivity is found to be greater than 5×10^{-6}, or 0.000005. The slightest admixture of any readily electrolyzable substance multiplies the conductivity of water enormously.

The products of electrolysis collect upon the two electrodes and have a tendency to greatly increase the resistance, especially if one or both products are gaseous. The Wehnelt interrupter is an example of a liquid resistance in which the current is actually rendered discontinuous by changes taking place at one of the electrodes.

The resistance of a liquid cell is, therefore, not always a true indication of the conductivity of the liquid.

The *influence of polarization* is reduced by using a rapidly alternating current and electrodes with specially prepared surfaces.

Platinized electrodes are prepared by immersing them in a 3 per cent. solution of platinum chlorid containing $\frac{1}{40}$ per cent. lead acetate, and sending a weak current of electricity at first in one direction and then in the other for about ten minutes. The surface of the platinum electrodes becomes coated with platinum black, which does not allow the gases to accumulate upon its surface to any extent, and thus greatly reduces polarization. Palladium black deposited upon the surface of the electrodes is also an excellent depolarizer.

Rapid alternation of the current, so that neither electrode is of one polarity long enough for gases to collect upon it, is a most effective means of preventing polarization.

Testing the Conductivity of a Liquid.—This is done by placing some of the liquid in a suitable glass or porcelain vessel, immersing suitable electrodes in it, and then, by means of a battery and small induction coil, Wheatstone's bridge, and adjustable standard resistance, measuring the resistance offered by the liquid cell to the passage of the current. As an ordinary galvanometer or milliamperemeter will not measure an alternating current, an electrodynamometer is used or, better still, a telephone receiver. The telephone receiver takes the place which the galvanometer would occupy in the ordinary use of the Wheatstone bridge, and indicates an exact balance, and consequently no current across the bridge when no sound is heard in the telephone.

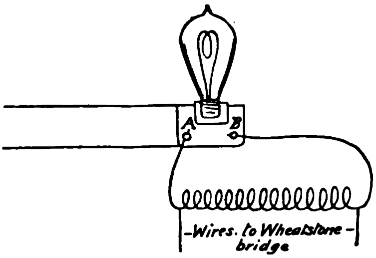

Fig. 137.—Use of the alternating electric-light current in testing conductivity of a liquid. A volt controller and the Wheatstone bridge are in series with the incandescent lamp.

The battery should consist of only one or two voltaic cells or dry cells. A storage-cell can be used with a large fixed resistance in circuit; or the alternating electric-light current can be used by introducing an incandescent lamp and a volt controller (Fig. 137). The volt controller has very little resistance, the object being to yield a difference of potential of only two or three volts between the wires leading to the Wheatstone bridge. The resistance employed in the volt controller being only two or three ohms, it is necessary to supplement it by the resistance of the incandescent lamp before it is safe to turn on the 110 volts alternating current. The series lamp-socket makes it a simple matter to connect an electric lamp for use as a resistance. The socket has binding-posts and the lamp is in series with any circuit which terminates at *A* and *B*. Disconnecting the wire at *A* and *B* or both extinguishes the lamp. A 16-candle-power lamp is screwed into the socket.

The rate of alternation in the electric-lighting current is not rapid enough to give a clear sound in the telephone receiver and consequently the electrodynamometer must be employed with this current. No induction coil is required.

The 110 volts direct electric-lighting current may be used in the same way, and a series socket and volt-controller form a simple and reliable apparatus if one has not a more elaborate apparatus, such as the author's table for obtaining the galvanic, faradic, sinusoidal, and other currents from the 110 volts direct current.

The shape of the vessel and the distance between the electrodes should vary to correspond with the conductivity of the different liquids to be tested. A U-shaped tube, Fig. 138, *a*, in which the two electrodes are separated by a column of liquid several inches in length, is suitable for testing the conductivity of a liquid which is a good conductor. The diagram *b* shows a vessel suitable for testing a liquid of very poor conductivity. The electrodes are fixed in position by wires which are sealed into glass tubes, the latter being partly filled with mercury. Conducting wires dip into the mercury and make perfect contact. The two glass tubes are solidly fastened in the hard-rubber cover of the jar and there is another hole through the cover for the introduction of a thermometer. The glass-covered stem of the lower electrode is shown in the diagram as passing through a hole in the upper electrode.

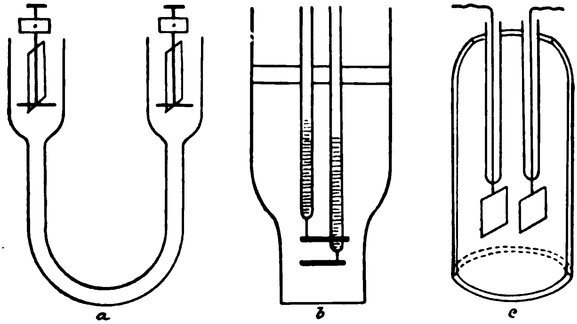

Fig. 138.—Vessels and electrodes for testing the conductivity of liquids: *a*, For liquids of great conductivity; *b* and *c*, for those more resistant.

The diagram *c* shows still another arrangement. The two electrodes are solidly fastened in a glass tube, open top and bottom, and can be immersed in a liquid contained in any sort of vessel.

The induction coil for use in these measurements should have only about 1000 turns of wire and its vibrating interrupter should give a musical note representing from 250 to 1000 vibrations a second. There should be a switch for turning the current off when not actually making the test, as the current heats the liquid. The telephone receiver should have a resistance of about 10 ohms. A difference of $\frac{1}{20}$° C. in the temperature of the liquid makes a difference of 0.001. It may be readily seen that if the measurement is to be exact down to thousandths, the liquid must be at exactly the proper temperature and must be kept there by a thermostat.

The *standard resistances* used in making the test include, first, a resistance box, which should give any number of ohms from 1 to 1000 by the adjustment of plugs introducing various resistance coils into the circuit. The longer resistance coils should, of course, be wound in such a way as to reduce the disturbing effect of self induction and capacity to a minimum, the first by having the wire doubled upon itself and the second by Chaperon's method of winding, each layer of the resistance coil wound in the opposite direction from the preceding layer. Secondly, the two other standard resistances are formed by the portions of a resistance wire on either side of an adjustable sliding contact. This may be a straight wire of platinum iridium alloy or of constantan, a nickel-copper alloy, 1 meter long and about ¼ mm. in diameter. Or, it may be a similar wire with perhaps only 25 mm. of straight wire, and its two ends forming resistance coils. This arrangement economizes space in the construction of the apparatus and is permissible because the measurements by the Wheatstone bridge are most accurate when the two parts of the slide wire resistance are nearly equal.

Fig. 139 shows the arrangement of the apparatus for the measurement of the resistance in the cell of liquid, and Fig. 140 gives the customary diagrammatic representation of the Wheatstone bridge and indicates the parts which correspond to the present arrangement.

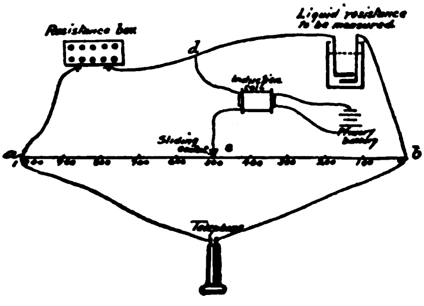

Fig. 139.—Wheatstone bridge used to measure conductivity of a liquid.

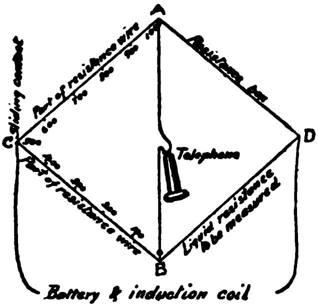

Fig. 140.—Conventional diagram of Wheatstone bridge as used to measure conductivity of a liquid.

Naming the different resistances DA, AC, DB, and BC, according to points between which they are placed, these are the same in both Figs. 139 and 140. According to the principle of the Wheatstone bridge, no current will flow across from A to B through the telephone receiver if the different resistances bear the following relation:

$$DA : DB :: AC : BC.$$

The test is made by setting the sliding contact at 500, making AC and BC equal; then, while the current is turned on and the telephone held to the ear and the other ear stopped, adjusting the plugs in the resistance-box until the minimum sound is produced in the telephone. After this the sliding contact is moved along the resistance wire in one direction or the other until the absence of sound in the telephone shows that no current is passing across the bridge. Then, from the values of AC and BC in millimeters and of DA in ohms we find by the usual proportion the value of the unknown liquid resistance in ohms. The telephone forms an extremely sensitive test for the presence or absence of an interrupted or an alternating current. It shows as slight a difference as $\frac{1}{10,000}$ between the potentials at the two sides of the Wheatstone bridge. It consequently affords a very exact measure of the different resistances. It does not, however, indicate the direction of the current flowing across the bridge, and consequently there is no mathematic guide to the direction in which the sliding contact should be moved. The latter is moved in one direction at a venture and the effect upon the loudness of the sound in the telephone is noted. If the sound becomes less, it means that the sliding contact is being moved in the right direction, and vice versâ.

The general arrangement is exactly the same when the direct 110-volts current with a suitable volt-controller is used to excite the small induction coil.

An electrodynamometer must be used instead of the telephone receiver if the slowly alternating electric-light current is used, as this does not give a satisfactory sound in the telephone.

To recapitulate. A unidirectional current cannot be used in measuring the resistance of a liquid because of electrolysis and rapid polarization. An ordinary galvanometer or milliamperemeter will not work properly with an alternating current. The telephone receiver has been found excellent for the purpose of detecting the presence of a current; and the best current for the purpose is the secondary current from a small induction coil of 1000 turns actuated by one or two dry cells or by an equivalent direct primary current from any other source. The secondary current from the induction coil is a rapidly alternating one.

One practical application of this test in medical electricity is in determining the electric conductivities of the urine and other animal fluids which vary in morbid states. Another is in the measurement of the resistance of the human body. When electrodes are applied to a cutaneous or a mucous surface, or actually puncture the tissues, we have to do with an electrolyte with some of the same characters as those of the liquids described in the last few pages, but even more complex. The resistance encountered by a direct continuous current, for instance, changes very much after the current has been flowing for a time, and is greatly modified by the passage of a faradic current. As in the case of liquids in glass jars the resistance to the flow of the current through the body is lessened in proportion to the size of the electrodes. The knowledge of the effect of varying conditions upon the resistance of the human body is of great importance as a guide to application of the proper current; voltage, alternating or direct character, frequency, and sometimes amperage, all have to be considered.

Electric Conductivity of Solids.—Metals and other good conductors transmit the current without evident change in their physical or chemic constitution, and at the same velocity as that of light. All substances, however, present some resistance, develop some heat, and undergo some chemic change.

Conducting Series.—The substances are arranged in the order of their conductivity:

Silver	Good conductors.
Copper	
Gold	
Zinc	
Platinum	
Iron	
Tin	
Lead	
Mercury	
Charcoal and coke	
Acids	Sometimes classed as conductors, sometimes as semiconductors.
Saline solution	
Sea-water	
Water	
The body	Partial or semiconductors.
Cotton	
Dry wood	
Marble	
Paper	
Oils	Non-conductors or insulators.
Porcelain	
Wool	
Silk	
Sealing-wax	
Sulphur	
Resin	
Gutta-percha	
India-rubber	
Shellac	
Paraffin	
Ebonite	
Glass	Varies much in power with the quality.
Dry air	Rarefied air stands higher on the list, according to its pressure.

Currents and Derived Circuits.—An electric current divides up among two or more conducting paths in proportion to their conductances. The latter are inversely proportional to their resistances. In the diagram (Fig. 141) a current C is supposed to be passing through the undivided portion of the circuit under the influence of an electromotive force E. R is the resistance in the undivided part of the circuit, and r' and r^2 are the resistances in the two circuits into which it divides.

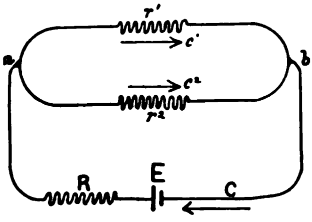

Fig. 141.—A circuit dividing into two derived circuits.

Then the current C, through the undivided part of the circuit, and c' and c^2, through the two branches or derived circuits, are found by the following equations:

$$C = E \frac{r' + r^2}{Rr' + Rr^2 + r' r^2}$$

$$c' = E \frac{r^2}{Rr' + Rr^2 + r' r^2}$$

$$c^2 = E \frac{r'}{Rr' + Rr^2 + r' r^2}$$

The current C through the undivided part of the circuit is, of course, equal to the sum of the currents c' and c^2, into which it splits at a certain point.

The currents c' and c^2 through the two divisions of the circuit or, technically, through the two derived circuits, are inversely proportional to their resistances. The current in the first derived circuit is to the current in the second as the resistance in the second is to the resistance in the first. If the resistance in the first derived circuit is twice as great as in the second, the current in the first circuit will be half as great as in the second.

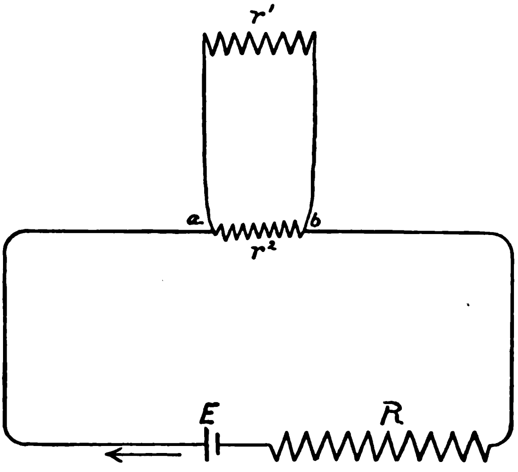

Fig. 142.—Principal circuit and shunt circuit.

The resistance R is supposed to include the internal resistance of the battery as well as that of the rest of the undivided part of the circuit.

The two derived circuits in the diagram (Fig. 141) are represented as starting at a certain place where the main circuit divides into these two, and terminating at another place by coming together to form by their union the continuation of the main circuit. This is a correct diagrammatic representation of every case in which there are only two derived circuits. There are apparent variations, such as when the main circuit seems to be unbroken and its single continuous wire is tapped by the attachment of the ends of a shunt or side wire at two points more or less near to each other. Fig. 142 represents such a case by indicating the existence of a resistance r^2 in that portion of the main wire between the two points of attachment of the side wire. This resistance may be great or small, but it is an actual quantity, and its relative amount, as compared with the resistance, r', in the principal wire, determines the proportion in which the current is divided between these two conducting paths. These are both known as derived circuits, and this is equally true of the circuit which is apparently a direct part of the undivided circuit, as of the circuit which is apparently only a side branch.

Another case which must be alluded to is when there seems to be no undivided circuit, as in Fig. 143. The two derived circuits, it is true, do spring directly from the poles of the battery, but the current through the battery itself is an undivided one and is equal to the sum of the currents through the two derived circuits. The latter currents are inversely proportional to the resistances in the two derived circuits. The resistance R of the undivided circuit is simply the internal resistance of the battery.

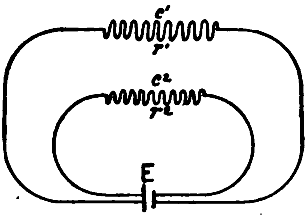

Fig. 143.—Two circuits starting from the battery.

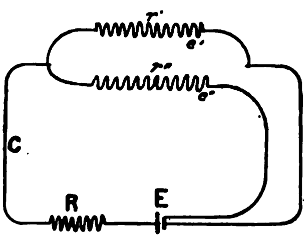

Fig. 144.—Single circuit at one pole of battery and divided circuits at the other.

Another case is seen when an undivided circuit leaves one pole of the battery, but the derived circuits do not reunite and are attached separately to the other pole of the battery. Here, Fig. 144, the resistance R includes the internal resistance of the battery and the resistance of the undivided part of the external circuit.

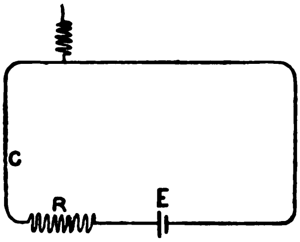

Fig. 145.—Undivided circuit with a wire attached at only one point and not forming a derived circuit.

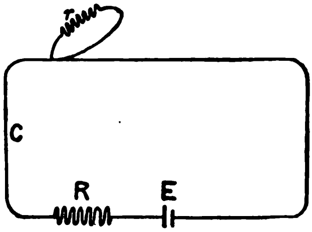

Fig. 146.—Loop starting and ending at the same point of a circuit and therefore transmitting no current.

Another case which may be considered is that in which a side wire is attached at either pole of the battery or at any part of the circuit, but the other end of this side wire (Fig. 145) does not lead to any part of the circuit. This side wire does not form a derived circuit and it transmits no current no matter how great or how little resistance it may have or what proportion its resistance may bear to that in the circuit. There is only a simple circuit with an electromotive force E, a total resistance R, which includes the resistance of the external circuit, and the internal resistance of the battery. The strength of the current C is the same at all parts of the circuit, both in the battery and in the external circuit, and is equal to E divided by R.

A loop of wire both ends of which are attached to the same point of a circuit (Fig. 146) does not form a derived circuit and does not transmit any current, no matter what its resistance, r, may be.

Fig. 141 (p. 175) is diagrammatic of every case in which there are one simple and two derived circuits, it being understood that the simple circuit sometimes includes the battery alone and sometimes the battery and an undivided portion of the circuit connected with one or with each pole. The resistance R of the simple circuit may be only the internal resistance of the battery, or if there are portions of a simple circuit connected with one or both poles of the battery, it will include their resistances also.

Any number of derived circuits would be represented by a corresponding number of branching lines. The current through the simple circuit is equal to the sum of the currents into which it splits in the derived circuits. The division of the current between the latter is inversely proportional to their resistances.

The conductivity of any circuit is the reciprocal of its resistance. If the resistance is r', the conductivity is $\frac{1}{r'}$. The combined conductivity of several parallel conducting paths or derived circuits is the sum of the individual conductances or the sum of the reciprocals of their individual resistances. Thus, if the resistances in three derived circuits are r', r^2, r^3, their combined conductance is $\frac{1}{r'}+\frac{1}{r^2}+\frac{1}{r^3}$; and if the resistances are all equal the *joint conductivity* is three times as much as the conductance of any one of these derived circuits. The *joint resistance* of a number of parallel derived circuits is equal to 1 divided by their joint conductance.

In the case of two parallel derived circuits with resistances r' and r^2 (Fig. 141, p. 175), *their joint conductance*$= \frac{1}{r'}+\frac{1}{r^2}$; *their joint resistance*$= \cfrac{1}{\frac{1}{r'}+\frac{1}{r^2}} = \cfrac{1}{\frac{r^2+r'}{r' \quad r^2}} = \frac{r' \quad r^2}{r'+r^2} = R'$.

The joint resistance of two derived circuits is equal to the product of their resistances divided by the sum of their resistances. When there are two derived circuits and the resistance, r^2, of one is known, we may calculate the resistance r' required in the other derived circuit in order to produce a joint resistance, R′, by the formula:

$$r' = \frac{R' + r^2}{r^2 - R'}$$

The total resistance of a circuit with two derivations r' and r^2 and a resistance R in the simple circuit is$=R+\frac{r'-r^2}{r'+r^2}$, or $=R+R'$.

A valuable application of this formula is in determining the relation between the resistance in a galvanometer and in a shunt. It seldom happens that a galvanometer is placed in a simple circuit so that all the current will pass through it. One reason for not doing this is that the galvanometer is usually so sensitive that any ordinary current, strong or weak, will produce the maximum deviation and, therefore, such a current must be divided by 10 or 100 or 1000 to come within the working limits of its indicator. The resistance of the galvanometer is usually great and it would involve a waste of power and an undesirable generation of heat if all the current were sent through it. A galvanometer, therefore, practically always forms a derived circuit, while a shunt forms another parallel derived circuit. The resistance in each is usually so calculated that the multiplying power of the shunt is either 10 or 100 or 1000; and very often these relations are adjustable, so that with weaker currents a lower, and with stronger currents a higher, multiplying power is used.

The calculation of the resistances of the galvanometer and the shunt in order to produce a certain multiplying power is important.

The total resistance R in the circuit represented in Fig. 147 is made up of the internal resistance B in the battery; the resistance of the galvanometer G, the resistance of the shunt s, and the resistance of the rest of the external circuit r. The resistance encountered by the current in passing the galvanometer and its shunt is known to be $\frac{G\times s}{G+s}$. The total resistance $R=\mathrm{B}+\frac{G\times s}{G+s}+r$, and the equations expressing Ohm's law become $\frac{E}{\mathrm{B}+\frac{Gs}{G+s}+r}=$ amperes; $E=C\left(B+\frac{Gs}{G+s}+r\right)$, volts; $\frac{E}{C}=B+\frac{G+s}{G+s}+r$ ohms $=$ total resistance.

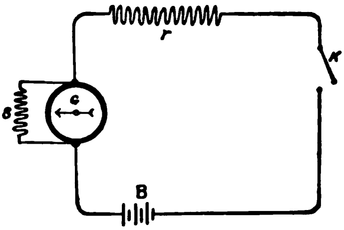

Fig. 147.—Relation between resistance in a galvanometer and its shunt.

If the galvanometer were in simple circuit and there were no shunt, but all the other conditions as to electromotive force and resistances were unchanged, the current passing through the galvanometer would be a certain number of times greater than the current which passes through the galvanometer when the shunt is used, and the current is thereby divided into two parts.

The multiplying power of the shunt is the ratio of the current, C, which would flow through the galvanometer if not shunted to the current C', which flows through it when shunted. The formula for the multiplying power is $\frac{C}{C'}=\frac{G+s}{s}=\frac{G}{s}+Q$. If the multiplying power, $\frac{C}{C'}$, is n, $n=\frac{G+s}{s}$; $s\,n=G+s$; $s\,n-s=G$; $s\,(n-1)=G$; $s=\frac{G}{n-1}$.

The resistance required to give a multiplying power of n is, therefore, $=\frac{G}{n-1}$.

The additional conductance of the shunt is added to that of the galvanometer and the total resistance in the circuit is thereby reduced.

If it is desired to keep the current strength down to the same number of amperes, a compensating resistance must be added in the simple circuit to make up the difference between G resistance and $\frac{G}{n}$ resistance, the joint resistance of the galvanometer and the shunt. The required compensating resistance is, $G-\frac{G}{n}$, or $G\,\frac{n-1}{n}$.

The Sensitiveness of a Galvanometer.—The degree of sensitiveness of a galvanometer or its *figure of merit* is determined by the resistance (Rf) it is necessary to place in circuit with it in order that one Daniell cell will produce a deflection of 1 degree of arc (Fig. 148). The *figure of merit* of a galvanometer may be found by varying the resistance R until 1 degree of deflection is produced, or it may be calculated from the number of degrees of deflection produced with a known resistance, R and one Daniell cell. If *d* is the number of degrees deflection in the case shown in Fig. 148, the resistance Rf, which must be introduced in order that the current shall produce one degree of deflection, is found from the equation $\mathrm{Rf} = d\,\frac{G+s}{s}\left(\frac{Gs}{G+s} + \mathrm{R} + \mathrm{B}\right)$.

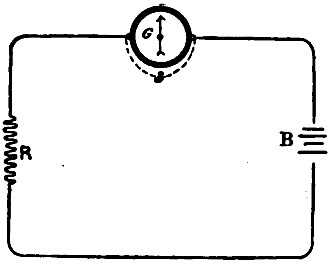

Fig. 148.—Measuring the sensitiveness of a galvanometer.

Galvanometers may be marked in degrees, *i. e.*, fractions of a circle, and if so, it is necessary to know their degree of sensitiveness in order that they may be used for measuring the strength of currents and indirectly for measuring electromotive force and electric resistance. The above method enables one to test this degree of sensitiveness, and it may be applied to any galvanometer, whether the strength of the current is proportional to the number of degrees of a circle in the angle of deflection or to some other mathematic function of the angle. The ordinary needle galvanometer undergoes deflections, which, with moderate angles, are directly proportional to the strength of the current; and, having once found the degree of sensitiveness of the instrument, it can be used as a milliamperemeter. To calculate the number of amperes indicated by one degree of deviation, divide the number of volts of electromotive force yielded by the Daniell cell by the total ohms of resistance, internal and external, in the circuit, which results in one degree of deviation.

The wire in an astatic galvanometer varies in size and in the number of turns according to the currents which it is designed to measure. The usual instrument for measuring voltaic battery currents consists of about 800 turns of insulated copper wire about $\frac{1}{8}$ millimeter or $\frac{1}{150}$ inch in diameter.

Such instruments, of course, have great electric resistance, and even when shunted so that the joint resistance of the galvanometer and shunt is only one-tenth or one-hundredth that offered by the galvanometer when unshunted; this joint resistance is still so large that it must be accurately known and taken into account in all the above measurements. This resistance may be obtained from the table on p. 217 if the diameter and the length of the wires in the galvanometer and the shunt are known.

A needle galvanometer is rendered ballistic or is damped by the addition of brass to the needle. This, by its weight, causes the needle quickly to assume a position of rest instead of oscillating back and forth like a pendulum before finally coming to rest in the position in which the influence of the current tends to place it. A needle galvanometer must always be held in a horizontal position.

Any needle galvanometer in which the needle is of large size, perhaps as long as the diameter of the coil, and in which the coils of wire are placed parallel with the meridian and hence with the needle before an electric current is turned on, will undergo deviations in which, within certain limits, the strength of the current is proportional to the number of degrees.

Thompson's (Lord Rayleigh's) mirror galvanometer is used to measure the smallest currents, as in testing the insulation of submarine cables and in observations upon animal and vegetable electrical currents. It has a large coil of many thousand turns of the finest copper wire, and a magnetic needle which is a piece of the hair-spring of a watch, about ⅜ inch in length. This carries a very small mirror and is supported inside the coil by a fine silk thread. A ray of light is reflected from the mirror and shows as a white spot on a graduated scale 3 feet away. When the light spot is at the zero mark the instrument is ready to measure currents. Within the ordinary limits of the scale the strength of the current is directly proportional to the amount of deviation. The value of each subdivision on the scale is found in the same way as the value of each degree in the ordinary needle galvanometer.

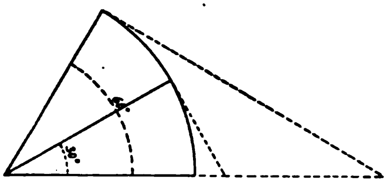
Fig. 149.—The tangent of an angle.

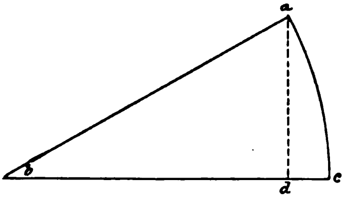

Fig. 150.—The sine of an angle.

Tangent Galvanometers.—These are galvanometers in which the strength of the current is proportional not to the number of degrees of angular deviation, but to the tangent of the angle of deviation. A geometric diagram (Fig. 149) will make this difference clear.

The tangent of an angle is the length of a line drawn from one end of the arc subtended by it, at a tangent to the curve (*i. e.*, at a right angle to the radius at that point), and continued until it intersects the prolongation of the radius which forms the other side of the angle. The angles represented in the diagram are 30 and 60 degrees respectively. One is twice as great as the other in fractions of the 360 degrees which go to make up a circle, but the tangent of the angle of 30 degrees is 0.5774 time the radius of the circle and that of 60 degrees is about three times as great, or 1.7321 times the radius of the circle. As the angle approaches 90 degrees, or a right angle, the values of the tangents vary even more rapidly. The tangent of 70 degrees is 2.7475;

that of 80 degrees is 5.6713; that of 85 degrees is 11.43, and that of 90 degrees is infinitely great. The current strengths indicated when the angles of deviation are 30, 60, 70, 80, 85, and 90 degrees are proportionate not to the numbers 30, 60, 70, etc., but to the numbers 0.5774, 1.7321, 2.7475, 5.6713, 11.43, and infinity. No current could be strong enough to produce a deviation of 90 degrees. A tangent galvanometer is used for measuring currents of low potential, but considerable quantity. It consists of a vertical copper ring which is placed parallel with the magnetic needle and which is to transmit the current, and surrounds a magnetic needle with a graduated circle beneath it. It is usually graduated in degrees and the tangents have to be looked up in a table; but it would be practicable to have the tangent values marked upon the scale. To give correct values the needle in a tangent galvanometer should not be more than $\frac{1}{12}$ or $\frac{1}{10}$ as long as the diameter of the copper ring.

The Sine Galvanometer.—This is a needle galvanometer by which the strength of the current is indicated by the sine of the angle of deviation instead of by the number of degrees of circular measure. The sine of an angle or of an arc of a circle is the line drawn from one end of the arc perpendicularly to the radius which terminates in the other end of the arc. In Fig. 150, *a–d* is the *sine* of the angle *b* or of the arc *a–c*, and if *b* is an angle of 30 degrees, we should find from a table of sines that the sine is 0.5 the radius of the circle. In angular and circular measurements the radius is always taken as 1 and so the *sine* of 30 degrees is 0.5. The *sine* of 60 degrees is 0.8660, and the *sine* of 90 degrees is 1. In a sine galvanometer there is the usual magnetic needle moving over a horizontal circle graduated in degrees—360 degrees in all. This circle and the magnetic needle are fastened at the center of a vertical ring around which are several turns of heavy, insulated, copper wire, through which the current is to be passed. The whole is supported on the vertical axis of a horizontal circle, forming its base and around which it can be turned. In measuring an electric current the vertical coil of wire is first placed in the plane of the meridian, and, therefore, parallel with the magnetic needle, the current is then turned on and the vertical coil is turned to a position parallel with the magnetic needle. The needle is now at a certain angle from the north and south direction under the influence of a current which in this new position exerts its force at an exact right angle to the direction of the magnetic needle. The strength of the current under these conditions is proportional to the *sine* of the angle of deviation. The sine galvanometer is suitable for very heavy currents.

The tangent and sine galvanometers both give readings which give directly only the comparative strength of different currents. To obtain absolute values in amperes or milliamperes it is necessary to ascertain the degree of sensitiveness of each instrument by experiment with an electric current, just as in the case of the ordinary galvanometer.

To test the degree of sensitiveness of any type of galvanometer with any battery and with a known resistance in the circuit it is only necessary to find the current necessary to produce one degree of deflection. An example of testing an arc galvanometer with a single Daniell cell has already been shown. To test a tangent galvanometer by means of a battery of 10 voltaic cells having an electromotive force known to be 10 volts, and a total resistance of 1000 ohms in the complete circuit, if the angle of deviation produced is 50 degrees, the following formula is used: $\frac{E}{R}=C$ or $\frac{10}{1000}=0.01$ ampere. This is the strength of the current producing a deviation of 50 degrees, and it bears the same relation to the current which will produce a deviation of 1 degree that the tangent (1.198) of 50 degrees does to the tangent (0.0175) of 1 degree. Hence the current which will produce a deflection of 1 degree is $0.01\times\frac{\text{tang. 1 degree}}{\text{tang. 50 degrees}}$; or $0.01\times\frac{0.0175}{1.198}=0.000146$ ampere.

To find the strength of current indicated by any other angle of deflection multiply the current 0.000146 ampere indicated by 1 degree into the quotient obtained by dividing the tangent of the other angle by 0.0175, the tangent of 1 degree.

The sensitiveness of a sine galvanometer is found in a similar manner by taking the different angles.

The divisions on the scale of the Thompson mirror galvanometer are entirely arbitrary, but they may be considered in the same way as degrees of an ordinary galvanometer, and the value of a deviation of one subdivision may be calculated from an observation made with any battery. The data required are the electromotive force, the total resistance, and the number of subdivisions of deviation.

The Limits of Accuracy of Galvanometers.—The current strength as indicated by a tangent galvanometer is more exactly proportional to the tangent of the angle of deviation when that angle is about 45 degrees than when the angle is either much larger or much smaller.

With all galvanometers the more nearly an angle of 90 degrees is approached, the less relation there is between the current strength required to produce that degree of deflection and any geometric function of the angle produced. In such a case either to measure the current or test the sensitiveness of the galvanometer it will be necessary to use a source of low potential or to shunt the galvanometer, so that only a small fraction of the current will pass through it.

Any galvanometer can be tested as to its degree of sensitiveness by placing it in the same circuit with a standard galvanometer and battery.

Amperemeters or Ammeters and Milliamperemeters or Millammeters.—These are galvanometers which are graduated by the manufacturer in amperes or milliamperes, instead of degrees. They are usually shunted, and the graduations on the scale indicate the total current through the galvanometer and its shunt. The milliamperemeters sold for electrotherapy frequently have two or more shunts of different resistance, and in this case there is a switch by which one or the other can be introduced. Numbers to which the handle of the switch points indicate the number by which the dial number must be multiplied to give the combined current through the milliamperemeter and shunt. Thus, in one position of the switch the numbered divisions on the dial may indicate milliamperes and the ten subdivisions of each represent tenths of a milliampere. The milliamperemeter may then measure currents from $\frac{1}{10}$ to 5 milliamperes. In another position of the switch (indicated by "× 10") the numbers on the dial are to be multiplied by ten, and each numbered division represents 10 milliamperes while the ten subdivisions of each of these indicate milliamperes. The meter may then register from one to fifty milliamperes. In another position of the switch (indicated by "× 100") the figures on the dial are to be multiplied by 100; each numbered division indicates 100 milliamperes and each of the smaller subdivisions indicates 10 milliamperes. The currents measured vary from 10 to 500 milliamperes. Still another position of the switch (marked "out") indicates that the current does not pass through the milliamperemeter at all. This is for use in experimenting (not upon a patient, but upon some other conductor) with currents of unknown strength, and which might damage the milliamperemeter. The arrangement of multiplying powers described above is the one adopted by the author for the milliamperemeter which measures all the different currents applied to the patient from the voltaic, faradic, de Watteville, and sinusoidal apparatus. It should be stated, however, that the galvanometer referred to is not of the magnetic needle type, but of the movable coil or d'Arsonval type.

The d'Arsonval Movable Coil Galvanometer (Figs. 151 and 152). —This instrument consists of a powerful permanent magnet and a freely suspended coil of fine wire, through which the electric current to be measured passes. The directive force is of the same nature as in the case of the magnetic needle galvanometer; it tends to place the magnet and the coil at right angles to each other, and does so in this case by moving the coil. The two poles of the magnet are concave and close together, and enclose a cylindric space in which the coil is pivoted so as to be free to move in either direction, but always in the plane of the horseshoe magnet. The meter may be placed in any position, and this makes it very much more convenient than the magnetic needle galvanometer. The movable coil is made of many turns of fine insulated wire wrapped around a metallic framework and contains a soft-iron core. The directive influence becomes manifest the moment the current begins to traverse the turns of wire in the coil and it tends to place the coil at a right angle to the direction of the lines of force in the magnetic field. This motion is opposed by the traction of the two spiral springs of zinc wire which, when no current is passing, keep the coil exactly parallel with the magnet, and the indicator needle carried by the coil exactly at the zero mark.

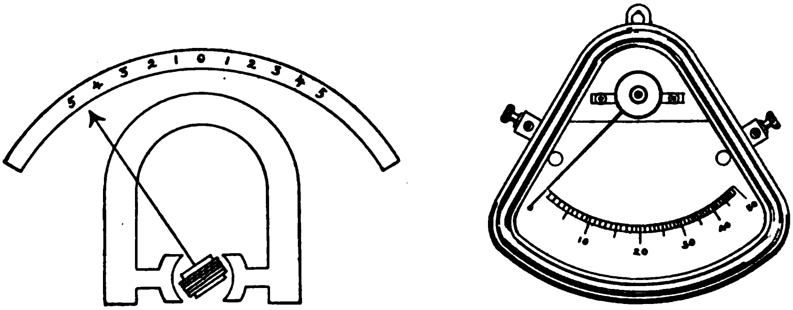

Fig. 151. Fig. 152.

Figs. 151 and 152.—D'Arsonval movable coil galvanometers.

An improvement over the two spiral traction springs consists in a single spring, like the hair-spring of a watch, coiled in a flat spiral. The spring is so adjusted that when it is not subjected to any outside influence it holds the coil and indicator exactly at the zero mark. It exerts a gradually increasing pressure as the coil deviates in one direction or the other under the influence of the electric current. The moment the current ceases to flow, the spring brings the indicator back to the zero mark. The direction in which the coil turns depends upon the direction of the current, and the connection of the milliamperemeter with the battery must, of course, be such that a deviation toward the + mark will occur with a positive current, and vice versâ. The scale may begin with the zero mark at the extreme left hand, and in this case the connections must be right in order to get any reading at all. If the connections are wrong and the milliamperemeter, therefore, is reading backward, the simplest plan is to unfasten the two wires, one leading to it from the battery and one leading from the milliamperemeter to the patient or apparatus and change their connections.

The directive influence is almost entirely that of the permanent magnet, and the movable coil is relatively very little affected by the earth's magnetism. This is the reason that a d'Arsonval milliamperemeter works equally well in any position.

The angle of deflection is regulated by several factors: the number of turns of wire and the strength of the current in the coil, *i. e.*, one component of the directive influence of the current; the strength of the magnetic field, *i. e.*, the other component of the directive influence of the current; the increasing tension and traction of the spring on the side that the indicator moves away from and the diminishing traction of the spring on the side toward which the indicator moves. The size and shape of the magnetic poles are such that the strength of their attraction is the same in every part of the magnetic field that is occupied by the coil in different positions. The directive influence of the current in the positions to which the coil is allowed to turn is such that the number of degrees in the angle of deviation tends to be proportional to the strength of the current. The effect of the spiral spring varies at different positions of the indicator. With a milliamperemeter registering from 0 to 5 milliamperes, the space on the scale between 0 and 1 is 1½ times as long as the space between 4 and 5.

The currents induced in the metal framework upon which the coil is wound tend to make the d'Arsonval milliamperemeter "dead-beat" or to cause the indicator to promptly come to rest at the angle of deflection corresponding to the strength of the current. This is much better than if the indicator were to oscillate back and forth over that point on the dial before gradually coming to rest. Of course, there is some slight oscillation even in a so-called "dead-beat" milliamperemeter. The momentum acquired by the coil under the influence of mutual attractions and repulsions between its electric current and the magnetic forces of the permanent magnet carry the coil past the point where these forces become nil, and even for a slight distance beyond, where these forces oppose its continued motion. It then ceases to advance and moves in the opposite direction. In a "dead-beat" milliamperemeter the oscillations back and forth over the proper mark are slight and the needle quckly comes to rest.

There is only one convenient and reasonably accurate way of graduating a d'Arsonval milliamperemeter, and that is by actual comparison with a standard milliamperemeter in the same circuit.

The d'Arsonval amperemeter is the same instrument, but designed to measure heavier currents, its divisions indicating amperes instead of milliamperes.

The usefulness of the different shunts in varying the multiplying power is the same as with the magnetic needle galvanometer.

The d'Arsonval Voltmeter.—The voltmeter on the d'Arsonval principle is made in different sizes and shapes. One is like a watch and has two terminals, one being a point which may be pressed upon one pole of the battery and the other an insulated wire leading to the other pole of the battery. One of this size and shape is very convenient for use in testing voltaic batteries. Each different cell may be tested in this way without disconnecting it at all from the rest of the battery.

In some batteries there is a switch-board upon which are metal contacts which lead to the poles of the different cells, and it is simply necessary to touch these two contacts without opening the battery case at all.

Still other batteries are more elaborately provided, and have double cell selectors by which the two poles of any individual cell, as well as of several cells, may be connected with a stationary milliamperemeter. In this case the cell selector is applied to the two contacts from the same cell: the terminals of the voltmeter are applied to the terminal binding-posts of the switch-board and the current is turned on. Each separate cell may be tested in this way or any number of the cells at once.

When a voltmeter is used to test a voltaic cell on open circuit, it means that the current is not allowed to pass in any other way. The poles of the cell may be disconnected from anything else, or if conducting cords are attached to the two poles, the other ends of the cords do not come together directly or through any other conductor. A battery of cells may be tested in the same way. The circuit is open until the voltmeter is applied to the positive pole of the cell at one end of the series, and the negative pole of the cell at the other end of the series. The voltmeter is in essence a galvanometer, and its deflection depends upon the strength of the current passing through it. As the voltmeter has a known resistance, the electromotive force can be calculated from Ohm's law $E = \frac{C}{R}$. It is customary, however, to mark on the dial the deflections which indicate the different voltages, and these have usually been determined by the manufacturer by comparison with a standard instrument. The absolute standard of electromotive force is obtained from a standard voltaic cell such as Clark's. The resistance of a voltmeter is usually a very large one compared with that of the normal circuit, so that the current is often but a fraction of the battery current when in actual use. Whether this resistance is all in the coils of the voltmeter, or whether it is partly in a shunt, depends upon the magnitude of the currents it is designed to measure.

Voltmeters about as large as a watch are designed to measure batteries with electromotive forces up to three volts, and yielding currents up to about 30 amperes. They have subdivisions as fine as $\frac{1}{5}$ volt, and are suitable for testing the electromotive force of single cells of any kind, especially wet or dry voltaic cells or storage-battery cells. The latter should be recharged before they have become entirely exhausted. To allow them to remain in use until the electromotive force falls to zero seriously impairs their efficiency.

The high resistance in the d'Arsonval voltmeter, a great many times that of the cell itself, makes it give sufficiently accurate results without the necessity for taking the internal resistance of the cell into account except in very exceptional cases, where extraordinary exactness is required.

It is essential to test the potential of a storage battery in operation, as well as when at rest. The electromotive force may prove to be about two volts per cell on open circuit, and still may fall very decidedly when the circuit is closed and the current is passing through the motor or x-ray coil. This is an indication that it is high time that the cell or cells so affected should be recharged.

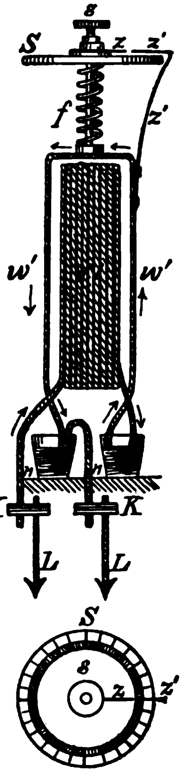

Fig. 153. — Siemens' electrodynamometer.

Larger voltmeters for measuring the electromotive force of powerful storage batteries with a potential all the way up to 110 volts, and yielding currents up to 20 amperes, are about $4\frac{1}{2}$ inches in diameter and proportionately thick and heavy. They look just like amperemeters, and have binding-posts to which wires from the poles of the battery are to be securely screwed.

It is perfectly practicable in any case to measure the electromotive force of a battery while in actual operation, and it is often very important to do so. The fact that the voltmeter has a very high relative resistance makes it transmit only an inconsiderable fraction of the current when it short circuits the entire apparatus by being placed directly between the terminals or the two poles of the battery.

The Electrodynamometer.—This is an instrument for measuring electric currents by the repulsion that exists between currents of electricity passing in an opposite direction through two parallel wires or parallel parts of the same wire. The form invented by Siemens consists of a vertical coil of heavy insulated wire W, and a single U-shaped piece of wire w', suspended over this by a spiral spring with a knob, s, at the top, by which the wire loop can be turned in either direction laterally. And this knob turns an indicator z over a graduated scale S. The wire w' also carries an indicator z', which passes over the scale S. The current enters the coil at a binding-post, K, and leaves the coil where the other end of the wire dips into a vessel of mercury. It then enters the single loop w', and leaves that at another vessel of mercury, from which again it passes by a short wire to another binding-post where it leaves the meter. The adjustment of the different parts is such that when no current is passing, both indicators point to the zero mark on the scale. When the current is turned on, the suspended loop w' is repelled and tends to be rotated and the knob s is to be turned sufficiently to make the action of the spiral spring keep the single loop *w′* in its original position and its indicator *z′* at zero. The extent to which the knob *s* must be turned is proportional to the square of the current strength. The scale may be marked in amperes after its degree of sensitiveness has been tested by the manufacturers; or it may be marked in degrees of a circle, and each reading will then require a calculation based upon the strength of current which has been found to be indicated by a deviation of one degree. The electrodynamometer is intended for the measurement of heavy currents used in electric lighting, but is less desirable in almost every way than the d'Arsonval amperemeter.

THE MEASUREMENT OF ELECTROMOTIVE FORCE

Quadrant Electrometer.—The electromotive force of a single cell of a battery or generator of any kind may be found by means of a quadrant electrometer, which is an instrument dependent upon the attraction and repulsion of two charged bodies: attraction when the charges are opposite, and repulsion when they are similar. A metallic disk is cut into four sections by two diameters at right angles to each other, and these sections are fastened on insulated glass supports so that they are all in the same plane, but are slightly separated from each other. Each quadrant is connected with the one directly opposite by a conducting wire. A flat aluminum needle is suspended over these quadrants by a fine metal wire from the inner coat of an inverted Leyden jar. The outer coat of the Leyden jar is grounded, while a conducting rod makes it practicable to connect the inner coat with a source of electromotive force. The needle is to be adjusted so that when the needle and all the quadrants are in the same electric state, the needle is at rest above and parallel to one of the diametric slits between the quadrants. When the needle and one pair of quadrants are similarly charged and the other pair of quadrants are oppositely charged, the needle deviates from its original position. Each end of the needle turns away from the quadrant which is similarly charged and toward the quadrant which is oppositely charged. It takes a certain amount of force to twist the wire by which the needle is suspended, and the extent to which the needle deviates is proportional to the electromotive force. The deviation is so slight that it is best observed by the reflection from a tiny concave mirror fastened to the needle and focusing the light from a lamp upon a screen about a yard away. One pole of the standard battery is connected with one pair of these quadrants and with the internal coat of the Leyden jar. The other pole of the standard battery is connected with the other pair of quadrants, which must be kept insulated. A careful note is made of the degree of deflection produced; and then the effect of the unknown battery is tried. The electromotive force is proportional to the degree of deflection. The instrument may be graduated in volts by the manufacturer or he may furnish a "constant" from which the electromotive force indicated by any degree of deflection may be calculated. $E = d \times$ constant (d being the number of degrees in the observed angle of deflection, the *constant* being the number of volts indicated by one degree of deflection and E the electromotive force of the cell).

The Equal Deflection Method.—By this method we note the deflection in a milliamperemeter produced by a standard cell of known electromotive force through a certain resistance, and then substitute for the standard cell the battery or other generator whose electromotive force is to be measured. The resistance is now varied until the milliamperemeter shows an equal deflection, and hence the same current as in the first observation.

If E′ represents the known electromotive force of the standard cell, and R′ the resistance used in the first observation, and E^2 the electromotive force to be measured, and R^2 the resistance found to be required in the second observation to make the milliamperemeter show the same degree of deflection; then $E^2 = E' \frac{R^2}{R'}$ volts.

It may be necessary to use a shunt, S^2, with the milliamperemeter when testing the electromotive force of a large battery, and then the equation would read:

$$E^2 = E' \frac{R^2 \frac{G + S^2}{S^2}}{R'}$$

Usually, the adjustable resistances introduced in the external circuit are so large that it is not necessary to take the internal resistance of the battery into account. Or, if it is considered, it will only be necessary to roughly estimate it. It is necessary to know the resistance of the galvanometer and of the shunt if one is used. The conducting cords are supposed to be short and of ample size, so that their resistance is so small as not to affect the result. The resistance R′ is made up practically of the resistance of the galvanometer and the variable resistance in the resistance box. These standard resistances are explained in detail under the heading of Wheatstone's Bridge. They form a necessary part of any outfit for accurate electric testing. They are coils of wire of various resistances which can be connected by the introduction of contact plugs or by a sliding contact so as to make readily available resistances from the very smallest to the largest. The various types of rheostat do not give a wide enough range or sufficient accuracy for this work.

The Equal Resistance Method.—The standard cell is first connected with a fixed resistance and a milliamperemeter, and the strength of the current in milliamperes C′ is noted. Then the generator whose electromotive force is to be measured is substituted for the standard cell, and the number of milliamperes C^2 is noted. The electromotive force of the two generators is directly proportional to the currents in milliamperes; and $E^2 = E' \frac{C^2}{C'}$.

A slight correction may have to be made for the internal resistances of the two batteries, but this is not necessary if the external resistance (in the resistance box and galvanometer) is comparatively large.

Lumsden's Method.—The standard cell E′ and the generator E^2 whose electromotive force is to be measured are placed at some distance apart, and are connected with each other so as to form a normal series. The zinc of the first is connected with the copper of the second, and again the zinc of the second with the copper of the first. A cross line passes from the middle of one connecting wire to the middle of the other, and any current in this cross wire passes through a galvanometer. One of the main conducting paths (Fig. 154) is a simple wire of ample proportions whose resistance is so slight that it does not have to be considered. Resistances are placed in the other conducting path between the two batteries. One of them, R′, is between the standard battery and the point where the cross wire leaves the main wire. This has a fixed standard resistance so large in comparison with the internal resistances of the batteries that the latter may be disregarded. The other resistance R^2 between the generator whose electromotive force is to be measured and the attachment of the cross wire is obtained from a resistance box by means of which any required resistance, large or small, may be employed. The resistance R^2 is varied until the galvanometer, G, indicates that no current passes through the cross wire A–B. The electromotive force of the generator E^2 is then $E^2 = E' \frac{R^2}{R'}$.

The reason for this is found in the fact that the influence of the electromotive force E′ tends to send a current through the main circuit in the direction of the large arrows, and through the derived circuit A–B, and its galvanometer in the direction of the small arrows *y*, *y*. The electromotive force, E^2, sends a current in the same direction through the main circuit, but in the contrary direction indicated by the small arrows *x x*, through the derived circuit. The tendency on the part of the stronger battery to produce a stronger current through the wire A–B and hence to produce a deflection of the galvanometer is offset by varying the resistance R^2. This resistance affects the current from both electromotive forces in the main wire, but only that from the electromotive force E^2 in the derived circuit A–B. The electromotive forces E′ and E^2 are found to be inversely proportional to the resistances R′ and R^2 required to produce absence of current in the derived circuit and its galvanometer. All electric measurements are most accurate within certain limits, which depend on different conditions. The most accurate results by this method of measuring electromotive force are obtained with large resistances, but within the following limits. The resistance used with the weaker battery should be as high as it can be and still have a change of 1 ohm from its correct value produce a readable deflection of the galvanometer. The resistance used with the stronger battery should not be so great that—

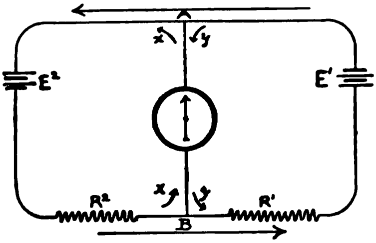

Fig. 154.—Lumsden's method of measuring for the electromotive force of a battery.

$$R_2\left(G\left(1 + \frac{E_2}{E_1}\right) + R_2\right) \text{exceeds } \frac{E_2{}^2}{E_1C}.$$

In the last fraction *c* is the figure of merit of the galvanometer, or the resistance through which an electromotive force of a Daniell cell (or practically 1.10 volts) will produce a deflection of one degree; and E^2 is the voltage of the stronger battery.

Law's Method of Condenser Discharges.—The amount of electricity with which a condenser of a certain capacity can be charged varies directly with the electromotive power. Fig. 155 shows the general arrangement of the apparatus for making this test. C is a condenser of a capacity of ⅓ microfarad (or a larger one, up to 1 microfarad, may be used). G is a galvanometer whose resistance is G ohms. S is a shunt past the galvanometer provided with a sliding contact by means of which the shunt may be disconnected entirely or it may offer a resistance varying from a small to a very large amount. The resistance in the shunt is S ohms. E is the battery and K the key by which the circuit is closed or opened. Two observations are required. In the first the smaller battery E' (volts) is used, and the galvanometer is not shunted. On pressing the key the condenser quickly becomes charged, and on releasing the key the condenser immediately becomes discharged. The latter effect produces a momentary current and a readable deflection of the galvanometer. In the second observation the larger battery E^2 (volts) is used, and the resistance of the shunt S is varied until the condenser discharge produces the same deflection of the galvanometer as in the first observation. The resistance then employed in the shunt may be designated as S^2 (ohms). Then, $E^2 = E^1 \frac{G+S^2}{S^2}$.

If the weaker generator is a standard cell with a known electromotive force, and the joint resistance in the galvanometer and its shunt is so large that the internal resistances of either battery need not be taken into account, then the electromotive force of the stronger battery is equal to that of the smaller battery multiplied by the multiplying power of the shunt employed.

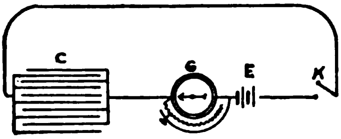

Fig. 155.—Measuring electromotive force by condenser discharges.

If the electromotive force to be tested is smaller than that of the standard cell, the unknown electromotive force would be tested first without shunting the galvanometer. And then the standard cell would be substituted and so shunted as to produce the same deflection. The small unknown electromotive force would then be found by *dividing* the number of volts produced by the standard cell by the multiplying power of the shunt employed with the latter.

If it proves necessary or desirable to use a shunt with each of the two generators, then the electromotive forces of the two generators are directly proportional to the multiplying powers of the individual shunts used with them.

The diagram (Fig. 155) shows these variable shunts only in a schematic way. In reality a resistance box would be used to furnish the wide range of resistances required for these measurements.

The well-known property which a condenser possesses of storing up large quantities of electricity renders it possible by this method accurately to measure electromotive forces so small that a continuous current through the same sensitive galvanometer would not produce a measureable deflection.

ELECTRIC RESISTANCES AND MEASUREMENTS

ELECTRIC MEASUREMENTS

General Considerations.—Sources of electricity are really means by which an electromotive force is produced, or a difference in potential is created between two points. This is known also as the *tension* of the current and is expressed in volts. It produces a flow of electricity through any conductor uniting the two points. The current has a tendency to establish a neutral condition by equalizing the electric state of the two points, and is analogous to the flow of water from a higher to a lower level. The amount of electricity transferred in a second is the strength of the current, is called its intensity, and is expressed in amperes. The rate of flow or the intensity of the current is determined by two factors—the tension of the current and the resistance of the conductor. It is directly proportional to the tension or voltage, so that if the voltage is twice as great, twice as many amperes of current will flow through the same resistance. It is inversely proportional to the resistance, so that if the resistance is twice as great, the same number of volts will cause only half the number of amperes to flow. All substances will transmit electricity, but some do so with so little resistance that they are called conductors, and are used for the purpose of transmitting electricity. Other substances are poor conductors. Still others are such poor conductors of electricity that they are called non-conductors, and are used as a means of insulating bodies which are charged with electricity or which are conducting an electric current.

In the case of a very good conductor, like copper wire, there is, nevertheless, a certain amount of resistance, and a certain proportion of the current seeking to pass through it is changed into heat by an effect analogous to that of mechanic friction. This resistance increases in proportion to the length of the wire and in proportion to its fineness. A fine wire presents a greater resistance than a coarse wire. A pound of copper in the form of a short bar may present very little resistance, while the same amount of copper drawn out into a long fine wire will present great resistance. The conductivity of any particular metal is always the same under similar circumstances, and is in inverse proportion to its resistance. The greater the conductivity of a metal the less resistance will be offered by a given length and thickness. The conductivity of different metals—and these are mentioned because they are the best conductors—is found by measuring the current in amperes which will pass through a standard length and thickness of a metal when connected with a source of the same potential that was employed in measuring the conductivity of the metal which is taken as a standard. The ohm as an absolute standard of electric resistance is the resistance at a temperature of 32° F. of a column of mercury one square millimeter in cross-section and 106.3 cm. long. The coulomb as an absolute standard of electric quantity is the quantity which when passed through a solution of nitrate of silver will cause 1.118 milligrams of metallic silver to be deposited. The ampere as an absolute unit of current flow or intensity is a current of one coulomb per second. The volt is not an absolute but a composite unit of potential or tension; it is an electromotive force which will cause a current of one ampere to flow through a resistance of one ohm. A Daniell cell produces an electromotive force of about 1.08 volts.

Ohm's law is of fundamental importance:

$$C = \frac{E}{R}; \quad \text{or } E = CR; \quad \text{or } R = \frac{E}{C}.$$

It means that the intensity of the current in amperes is equal to the electromotive force in volts, divided by the resistance in ohms. One or two examples may be given.

If the electromotive force is 110 volts and the resistance 10 ohms, the current strength will be 11 amperes:

$$C = \frac{E}{R}; \quad C = \frac{110}{10} = 11 \text{ amperes.}$$

If the resistance is 1 ohm and the intensity or strength of current flow is 10 amperes, the potential or tension is 10 volts:

$$E = CR; \quad E = 10 \times 1 = 10 \text{ volts.}$$

If the intensity or rate of current flow is 15 milliamperes $\frac{15}{1000}$ of an ampere, or 0.015 ampere, and the electromotive force, or tension, or potential is 7 volts, then the resistance is:

$$R = \frac{E}{C}; \quad R = \frac{7}{0.015} = 466.666 \text{ ohms.}$$

Values of R, E, and C, about like those in the last example, are found in the application of the voltaic current to the human body. The values in the first example, 110 volts, etc., are like those sometimes found in *x*-ray work; and those in the second example, 10 volts, 10 amperes, and 1 ohm, are like those occurring in the use of the galvano-cautery.

These relations are universally true, although either E or R may be a composite instead of a simple quantity. The measurement of electric quantities, strength of current, potential, or resistance almost invariably depends upon the application of this law; and the construction of all electric apparatus is guided by it.

The **voltameter** is an instrument by which the quantity of electricity which has flowed in a given time is measured by the increase in weight of a silver plate from the deposit of metallic silver upon it. This instrument is really a measurer of coulombs, because the number of grains of silver deposited is the same for the same number of coulombs whether the current is at the rate of 1 coulomb per second or 1 coulomb per minute; that is, 1 ampere, or $\frac{1}{60}$ ampere.

One coulomb liberates 12 cc. of hydrogen gas. A water voltameter may be graduated in cubic centimeters, or directly in coulombs.

The **watt** is a unit of electric power and is the power exerted by a current of 1 ampere with a pressure of 1 volt. A 4½ kilowatt transformer is one actuated by a current of 4500 watts, and this may mean 100 volts and 45 amperes; or any numbers the product of which will be 4500.

The **wattmeter** is designed to measure the power consumed in any apparatus through which an electric current, especially an alternating current, is passing. In the case of a direct and uninterrupted current of known and constant voltage and amperage passing through an apparatus of known and constant resistance, no separate wattmeter is required. The number of volts multiplied by the number of amperes gives the number of watts. But with an alternating current or with a direct current which is interrupted, as by a Wehnelt interrupter, in such a way that it is difficult to say during just what part of each period the current is flowing and work is being performed, a wattmeter serves to measure this power.

The principle of the wattmeter is similar to that of the electrodynamometer (p. 187). One wire coil in the wattmeter is of high resistance, and is connected in shunt to the apparatus, while another separate coil of wire is connected in series with the apparatus. One of these coils is fixed in position, while the other is suspended in such a way that its turns are normally parallel with those of the fixed coil. The flow of the current causes a repulsion between these two coils, and the knob at the top of the suspension cord is turned until the coils are brought to a state of parallelism. The dial upon which the knob is turned may be graduated in watts. The current in the high resistance coil is proportional to the difference in voltage at its two extremities, and the amount of torque or torsion of the suspension cord required to overcome the repulsion between the two currents is proportional to the product of the two currents. The torsion is, therefore, proportional to the voltage multiplied by the current passing through the apparatus to be tested.

The **galvanometer** is an instrument depending upon the deviation of a magnetic needle or of a freely suspended active coil under the directive influence of a current of electricity and a fixed permanent magnet. The graduations upon the dial indicate the position of the needle when there is a current strength of such and such numbers of amperes, as determined by direct or indirect comparison with a voltameter. The galvanometer is a measurer of amperes. The current strength or the number of coulombs per second has everything to do with the figures which it indicates. One coulomb per minute flowing for five minutes will not give at all the same deviation of the needle as 1 coulomb per second flowing for five seconds. The first strength of current would be indicated as $\frac{1}{60}$ ampere, and the second as 1 ampere. In fact, the instrument is usually called an amperemeter or a milliamperemeter, according to whether its graduations indicate amperes or thousandth parts of an ampere.

The **voltmeter** is similar in construction to a galvanometer, but has a great many turns of fine wire, and thus presents in itself a great resistance to the passage of an electric current. The needle swings over a dial the graduations on which indicate volts. These figures may be obtained in two different ways: one is by the use of a standard source of electromotive force, such as the Clark voltaic cell, which is known to give just exactly 1.434 volts. The other method is by using a galvanometer in circuit with the voltmeter. The resistance of both instruments must be found either by test or by calculation (the resistance of so many feet of copper wire of such a size). If the galvanometer shows that a current of 10 amperes is flowing and the resistance is known to be 11 ohms, then there is a tension of 110 volts, and the place on the dial of the voltmeter to which the needle has deviated would be marked 110 volts. A voltmeter is usually placed not in series with the other apparatus or with the patient, but is connected directly with the two terminals from which the current is distributed. The amount of deviation of its needle indicates the potential in volts. The needle really deviates according to the strength of the current or the number of amperes passing through the uniform resistance of the large number of turns of wire in the voltmeter, and, according to Ohm's law, the number of amperes must be directly proportional to the number of volts when the resistance is uniform. If the voltage is uniform, as in the case of the 110-volt electric-lighting current, there is no need to have a voltmeter; an amperemeter is required to show the strength of the current, and indirectly the resistance in the circuit. If the voltage and the resistance are both uniform and are known, neither voltmeter nor amperemeter is required; the current strength is uniform, and can be calculated from the other two factors. If the voltage is variable, but the resistance uniform, a single instrument, the regular amperemeter, will act also as a voltmeter. Two sets of figures would appear upon the dial, the outer set indicating volts and the inner set amperes. Such a meter would give a correct reading in amperes in any circuit, but its reading in volts would be correct only in a circuit having exactly the same resistance as the one for which it was originally tested and graduated. A separate voltmeter having in itself a large resistance may be placed between the terminals leading to any circuit, and will give correct readings. It is almost indispensable when the current is derived from a variable source of electromotive force, and when the resistance in the circuit is also variable.

Dynamic electricity or electricity in the form of a current, as derived directly from a voltaic battery, a storage battery, or a dynamo, will follow two or more conducting paths between the terminals of the battery in inverse proportion to the resistance in the different paths. Thus, if there is a battery of storage-cells with an electromotive force of 30 volts and two separate lines of wire and apparatus connected with its terminals: if the two circuits have the same resistance, the same strength of current will flow through each, while if one has a hundred times the resistance of the other, only one one-hundredth as much current will pass through it as through the circuit with less resistance. This rule about the relative strength of current carried by branching circuits is perfectly simple and straightforward. It forms the basis for the employment of the Wheatstone bridge in measuring the resistance of a conductor.

The *Wheatstone bridge* is an arrangement of conducting wires, resistance coils, and a galvanometer through which a current of electricity is sent from a suitable battery. The current may follow two paths, in one of which different carefully tested resistances are introduced, and in the other is introduced the resistance which is to be measured. The word *bridge* has reference to the position of the galvanometer in relation with these two circuits. The galvanometer is inserted in a line which bridges across between the two circuits, and a current flows through it from the circuit in which there is the least tension. We might use the face of a clock as a diagram to illustrate the principle of the Wheatstone bridge. Twelve o'clock would indicate the point at which the positive wire from the battery is connected with the wire circuit, and 6 o'clock the connection with the negative wire. The current passes between these points along two different paths: down along the right-hand margin and down along the left-hand margin of the dial. At the center of the clock face is the galvanometer, whose wires pass from the 3 to the 9 o'clock mark. When the conditions are the same at these two marks, no current passes through the galvanometer, but when there is a stronger current in consequence of a greater potential at 3 than at 9, the galvanometer will show that a current is passing through it from the 3 to the 9 o'clock mark. The resistance to be measured is introduced at 1 o'clock, and the different standard resistances are introduced at 11 o'clock. The latter resistances are increased or diminished until they are equal to the resistance to be measured, just as standard weights are used to weigh an object. Equality between the two resistances is indicated when no current passes through the galvanometer.

Another method of measuring an unknown resistance is by the use of a voltmeter and an amperemeter, as already indicated at p. 193. The resistance in ohms is equal to the voltage divided by the amperage.

The Potentiometer.—The same balancing of electromotive force acting in opposite directions upon a galvanometer forms the basis of the potentiometer. This is an instrument for measuring electromotive force not based upon the strength of current which it will send through a known resistance, as in the case of the voltmeter, but by opposing it to known standard electromotive forces until the absence of a current through the galvanometer indicates equality between the two electromotive forces.

A Clark's cell is a usual standard for measurements of electromotive force.

The current strength or number of amperes produced by a voltaic battery is equal to the electromotive force of the battery divided by the entire resistance in the circuit. This resistance is made up of the internal resistance in the battery itself and the external resistance found in every part of the circuit, from one terminal of the battery to the other, including conducting cords, measuring and regulating apparatus, and the patient's body in electrotherapy.

The internal resistance is very important in the case of a voltaic or a storage battery. Quite a little calculation is sometimes necessary to decide how to set up a battery of either of these types so as to produce the greatest number of amperes of current. Setting up these cells in series, positive terminal of one connected with the negative of the next, multiplies the electromotive force of each cell by the number of cells, but it also multiplies the internal resistance of one cell by the number of cells. Setting them up in parallel, the positive terminals of all the cells united to one common conducting cord and the negatives all united to the other divides the internal resistance of one cell by the number of cells, but leaves the electromotive force of the battery equal only to that of a single cell. Connection in parallel series multiplies the electromotive force and the internal resistance of one cell by the number of cells in each series, but modifies the result by also dividing the internal resistance by the number of parallel series. When the external resistance is very great, as in the case of the human body, the greatest strength of current is produced by setting up the battery in series. The electromotive force is increased in proportion to the number of cells, while the additional internal resistance may perhaps add only 1 or 2 per cent. to the total resistance. The current strength in amperes is then almost exactly proportional to the number of cells in the series.

In other cases, as for most cautery purposes, it is desired to send a large number of amperes through a small external resistance, and here the additional electromotive force of a series battery would be offset by its increased internal resistance. An increased current would be obtained by parallel connection, diminishing the internal resistance; and in this particular case the total resistance is almost in inverse proportion to the number of cells, while the electromotive force remains unchanged. For diagnostic illumination and running motors for different apparatus and for electrolysis and for some cautery purposes the combined parallel series connection is the best.

The general law governing the arrangement of a voltaic or a storage battery is that the greatest current is obtained when the conditions are such that the internal and external resistances are equal.

In the case of a dynamo, the electromotive force is usually so great in proportion to the internal resistance that very often the only electromotive force to be considered is the voltage at the two terminals of the dynamo, and the only resistance to be considered is that in the external circuit.

Rheostat.—The regulation of the current from a voltaic battery for therapeutic application may often be accomplished by selecting the proper number and arrangement of cells employed, but a rheostat or adjustable resistance is an invaluable addition. It is often necessary to use heavy currents which are free from any discomfort when turned on and off very gradually, but which produce disagreeable shocks if suddenly increased or diminished. A suitable rheostat enables one to change the strength of the current more gradually than any cell selector. The employment of the powerful and sometimes even dangerous current from a dynamo requires the use of a rheostat or of a volt controller to reduce the amperage or the voltage of the current before it can be applied to the human body at all. Here the rheostat is used not only to turn the current on and off gradually, but also to limit the amount which can reach the patient. There is no convenient means of regulating the power of the dynamo to the requirements of each therapeutic application, and so different instruments are employed to modify the current before it reaches the patient.

The *principle of the rheostat* is exceedingly simple. The wire leading to the patient is cut, and between the two cut ends is fastened a variable resistance. This may consist of a vessel of water into which dip two wedge-shaped pieces of carbon or some other conductor. The carbons are connected with the two cut ends of the wire, and the current encounters a greater resistance when they dip slightly into the liquid, and a smaller resistance when the surface of contact is increased by dipping the triangular carbons deep into the liquid. Other rheostats consist of strips of graphite inlaid in hard rubber, a sliding contact determining the length of graphite through which the current must pass. Others are made of coils of wire or metal ribbons of a material like iron or German silver, long and thin enough to present the requisite amount of resistance. The length of resisting medium through which the current must pass is regulated by means of a sliding contact. Still another rheostat depends upon the fact that a change in the conductivity of carbon takes place under varying degrees of pressure. Turning a thumb-screw in one direction or the other increases or diminishes the resistance.

The *liquid*, the *carbon compression*, and the *graphite rheostats* are seldom used except for lighter electrotherapeutic currents, and the wire and the ribbon rheostats are necessary for the heavier currents required to operate motors and *x*-ray coils. A simple and effective rheostat is formed by one or more incandescent electric lamps arranged in series so that the lamp and the electrotherapeutic apparatus form a single continuous circuit. No matter how little resistance there may be in the rest of the circuit, a 16-candle-power lamp limits the strength of the current to about ½ ampere.

A rheostat may consist of one or more incandescent electric lamps arranged in series, so that the lamps and the electrotherapeutic apparatus form a single continuous circuit. A series of lamps will limit the current to any small fraction of an ampere that may be desired, while a number of lamps arranged in parallel will permit the passage of as great a number of amperes as may be desired, for instance, for charging a storage battery.

The amount of current which will pass through a series of resistances is equal to the electromotive force divided by the sum of all the resistances. When, however, these resistances are arranged so as to form parallel paths for the current, the conditions are practically reversed. The amount of current which will pass is equal to the sum of the currents which the different paths would transmit separately; so that in the case of the 110-volt electric-lighting current which is supplied by a constant potential dynamo, a series of 20 16-candle-power lamps will transmit a current of about $\frac{1}{40}$ ampere; while the same 20 lamps arranged in parallel would transmit about 10 amperes.

Very great resistances which are easily varied may be obtained by drawing several parallel lines with India ink upon strong drawing paper. These are close together, but of decreasing length. A metal clamp touches all the lines at one end, and a metal contact may touch from one to all of these lines according to where it is applied. Resistances varying from 0.01 to 20,000. meg-ohms are obtained in this way. The current transmitted varies from 0.4 ma. downward.[1]

The **volt controller** or reducer of potential depends on an entirely different principle. The electric current flows through a circuit from a region of high potential to one of low potential, very much as water flows through a tube from a high to a low level. If the electric circuit is made up of a single long wire having a uniform resistance throughout, there will be a uniform fall in pressure all along the line. If the difference in level between two points along the line is a certain fraction of the difference in level between the ends of the line, the difference in pressure between these two points will be the same fraction of the difference in pressure between the ends of the line. For example, if the difference in potential between the two poles of the dynamo is 110 volts, the difference in potential between one pole of the dynamo and a point half-way along the resistance will be only 55 volts. This means that a voltmeter connected with one pole of the dynamo and a point half-way along the external resistance would register a tension of 55 volts. An apparatus connected with these two points would receive a current the strength of which would be found by dividing 55 volts by the resistance of the apparatus in accordance with Ohm's law. The same 55 volts potential can be obtained by making the connection with two points anywhere along the main line, providing that half the resistance in the main line is included between these two points. Any fraction of the original 110 volts may be obtained by connecting the apparatus at points along the main line which include between them the required fraction of the resistance in the main line. The volt controller is an apparatus for

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[1] F. A. Aust, Phys. Zeitschr., 12, 1911, 752.

regulating the voltage supplied to a medical apparatus by connecting it with points along the main line between which a variable portion of the resistance in the main line may be included. The resistance in the main line consists chiefly of a resistance coil in the volt controller itself and the contacts are made by moving a contact spring along over the different turns of wire. If both terminals of the medical apparatus are in contact with the same turn of wire in the volt controller, there will be no difference in potential, the voltage in the therapeutic apparatus will be zero, and no current will flow through it. Moving the contact to different points so as to embrace more and more of the resistance in the main line, the potential supplied to the medical apparatus may be varied from 1 up to 110 volts (Fig. 156).

A **shunt circuit** has many important applications in electrotherapeutics besides that of a volt controller. It is a conducting circuit joining two points in a conductor through which a portion of the current may pass. The intensity or amperage of the current through the two conducting paths is in inverse proportion to the resistances in the two. If one has a hundred times the resistance of the other, only one one-hundredth part as much current will pass through it as through the other parallel path, with less resistance. The tension or voltage at the two points of junction is the same for both circuits, and the strength of the current in each is absolutely regulated by the resistance.

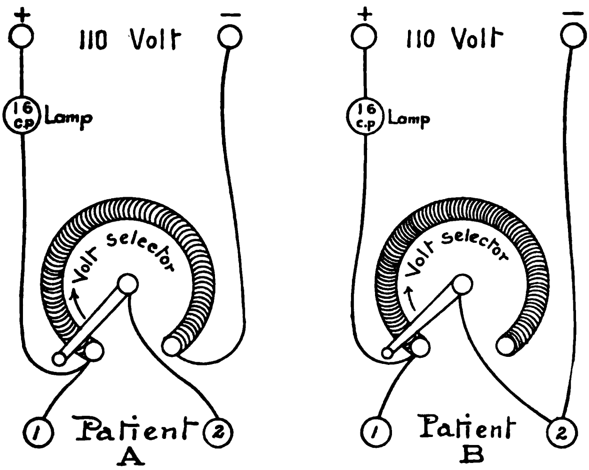

Fig. 156.—A is the most common connection, but B is preferable. A, Weston millameter connected with A, 1 and 2, will show more or less current according to position of R. When it is connected with B, 1 and 2, the position of R will not change number of milliamperes, showing that B is a volt selector, and not a rheostat.

Another important application of the shunt is in connection with the galvanometer or amperemeter. The heavy currents used for x-ray coils would quickly heat up and destroy the fine wire in a galvanometer, and, besides the injury to the meter, its resistance would occasion a great waste of power. And then, again, the directive influence of such a powerful current passing through the many turns of an amperemeter would be entirely too great for practical purposes. The maximum deviation would be produced by the weakest current ever employed for such purposes, and one could not read on the meter the different additional strengths of current. In fact, an instrument of this kind is so delicate in construction and so sensitive to the directive influence of the current that it is fitted to transmit milliamperes or thousandths of an ampere rather than whole amperes. To fit it for the measurement of currents varying from 1 to 50 amperes, the amperemeter is placed in shunt. A metal strip passes directly from one binding-post of the amperemeter to the other, and a very large portion of the current passes through this, while a very small portion passes through the winding of the amperemeter. The exact fractions of the current passing by these two different paths between the positive and negative binding-posts are determined by the very small amount of resistance in the metal strip and the very large amount of resistance in the many turns of fine wire in the winding of the galvanometer.

Another type of amperemeter for heavy currents has only a very few turns, or possibly a single turn, or even a straight bar in relation with a movable magnetic needle. It is for currents of such great amperage that it is not necessary to multiply their directive influence, as in the ordinary galvanometer. These are not, however, the currents employed in electrotherapeutics, but those employed in the transmission of power, hundreds or even thousands of horse-power.

The *voltage and amperage* of electricity from different sources, and as used for different purposes, differs very widely. A single voltaic cell has an electromotive force of about 1½ volts, differing somewhat according to the electrodes and electrolyte employed in its construction. The amperage of the current from a single voltaic cell varies from a maximum of about 30 amperes on short-circuit to a minimum when there is very great resistance in the external circuit. A battery or any other source of electric current is said to be short-circuited when the two terminals are united by a short length of a good conductor; in other words, when the external circuit has practically no resistance. Under these circumstances the number of amperes of current will be found to vary decidedly with the size and character of the cell. Theoretically, the amperage in this case would be found by dividing the electromotive force in volts by the internal resistance in ohms. The result will be from a small fraction of an ampere to 20 or 30 amperes, according to the type and size of the different voltaic cells in ordinary use. The larger the surface of zinc exposed to contact with the electrolyte, the less the internal resistance, and consequently the greater the current strength.

When the current from a single voltaic cell is applied to the human body, on the other hand, the external resistance becomes about 1000 ohms, and is so very much greater than the internal resistance that it forms the only considerable factor in the calculation of the current strength. The current strength will be about 1.5 milliamperes (1½ volts divided by about 1000 ohms), and it will not vary appreciably with the size of the voltaic cell. It would vary, of course, with different types of cell with different electromotive forces. A current of this voltage and amperage can hardly be detected when applied to the unbroken skin of the hand; but when applied to more sensitive parts, such as the teeth, it is readily perceived, and any stronger current is painful. Such a current produces scarcely a visible spark when the contact is made or broken. It may produce electrolysis or chemic decomposition in a solution through which it passes. The same voltage applied to a small electric lamp, like that of a cystoscope, will slightly heat its filament, and here the size of the voltaic cell will have a great influence upon the strength of the current and its heating and luminous effect. The same remarks apply to the effect of a single voltaic cell in heating a cautery point.

For the majority of direct *electrotherapeutic applications* an amperage of from 10 to 15 milliamperes of current is required, and with the ordinary resistance of the body this implies a tension of 10 or 15 volts. To obtain such a current from voltaic cells, several of them—about 10—must be set up in series, so as to secure their combined electromotive force. The current strength or amperage is approximately multiplied by the number of cells; for though their internal resistance is also multiplied, the latter resistance is very small as compared with the resistance of the human body. A current of this strength produces a sensation and other physiologic effects wherever applied. It will produce, however, only a very small spark on making or breaking the circuit, and for application to the human body large or small cells will produce an equal current. The same 10 cells with their 15 volts potential will produce excellent lighting and heating effects; in fact, this voltage is more than sufficient for endoscopic lamps and cautery points. For cautery purposes especially, the cells should be large, as from 10 to 20 amperes of current are usually required. Or the series may consist of a number of parallel sets of smaller cells.

The heavier currents for *x*-ray work may also be obtained from a voltaic battery or from a storage battery. In either case the cells are arranged in series to produce a potential of 10 or 12 volts, and the cells should either be large enough to yield about 10 amperes, or else two or more in parallel will have to take the place of each one in the series.

Arc-lamps and electric motors may be run by currents from a voltaic battery. The lamp requires 50 to 100 volts and 5 to 50 amperes. Both this and the electric motor are much more economically and conveniently run by a current from a dynamo than from a voltaic battery.

The 110-volt direct current from a dynamo gives one a disagreeable shock when any part of the body is introduced into the circuit, for instance, by touching the fingers to two bare bind-posts to see whether there is any current. It will arc across a considerable fraction of an inch at the break, and if it is turned on and off by a key, this should have a spring producing a quick break. This is to prevent the formation of an arc, which would occur if the two contact surfaces were slowly separated. An arc would melt and ruin the contact surfaces. The 110-volt direct current will not spontaneously leap across a space of even an eighth of an inch, and any good insulation, such as a layer of gutta-percha an eighth of an inch thick, covered by a braided fabric of silk or cotton, will prevent the current from escaping from one wire to the other, even if the covered wires are twisted together. This is often done for convenience, so as to be handled like a single cord, and even single cords of gutta-percha about half an inch in diameter are made, inclosing both wires. The fact that such an insulation must eventually become cracked and porous in spots does not mean that the current will necessarily leap across at such a point. Even a porous covering will suffice as long as the two wires are held at an appreciable distance from each other, and no good conductor extends from one to the other. This current may be short-circuited by cutting a charged double conducting cord with a penknife. Both insulating layers are cut through, and the steel coming in contact with both wires allows the full force of the current to pass through the very small resistance of the knife-blade. The result is startling, and may be disastrous. An excessively strong current passes across this small space, and tremendous heat is generated, burning a piece out of the knife-blade, not merely fusing, but vaporizing, the steel. The wires at this point are destroyed in the same way, and the safety fuses all along the line are burned out. This brings the flow of electricity to an end, and saves the house from being set on fire. The wires throughout the house would get so hot from the passage of a short-circuited 110-volt current that in a few minutes they would set fire to the woodwork. The same undesirable experiment may be made by holding a knife or a key against any exposed parts of the two wires, or the metal parts of a motor, or a switch, or the terminals of a coil. The same thing may happen from one of the wires becoming loosened in some way, and its bare end coming in contact with the bare end of the other wire, or with some metallic part of the apparatus connected with the other wire. About almost every electric apparatus to be run by the 110-volt current there are portions exposed to the possibility of short-circuit. Such portions, switches especially, should be separated from any inflammable structure by a marble or slate base. Do not bring any metallic object near any exposed part of the wire or apparatus, and in making the necessary adjustment of switches and rheostats touch only the insulated handle provided for that purpose.

A current of this voltage will pass across a considerable space if the contact is once made, and there is so little resistance in the circuit as to permit the flow of a large number of amperes, and the contact is slowly broken. This is the principle upon which an electric arc is produced. The same voltage is not apt to cross even a small space before the contact is made, and a very slight imperfection in the contact may prevent the current from passing. There are two reasons, therefore, for having the wires soldered together at every permanent joint all along the line. An incomplete connection might either prevent the current from passing or the wires might separate during the flow of the current, and the resulting arc set fire to woodwork or gas.

The wiring for an installation using the 110-volt direct current should comply with the regulations of the U. S. National Board of Fire Underwriters in order to be safe from risk of fire, and it then does not add anything to the cost of fire insurance. In many places it is a criminal offense to turn on the current at all until the wiring has been inspected and found to comply with these regulations. A pair of No. 14 copper wires are suitable for one to eight incandescent lamps. An *x*-ray apparatus should always have its own pair of wires leading from the mains, and not tapped for lamps or any other apparatus. They should be a pair of No. 10 wires. This is also the proper size for the powerful arc-lights employed for phototherapy.

Electric-light and Power Service.—The commercial arrangement for generating direct current for electric-light and power service in cities is usually as follows: Two 110-volt dynamos are connected in series; this gives a three-wire distribution service. The middle wire is called the neutral one. If the house is to be supplied with 110 volts, then the three wires are brought into the basement and connected with the meter. In order to obtain a 110-volt current, connections are made with the neutral and one outside wire. If a 220-volt current is desired, then connections are made with two outside wires. The size of the distributing wires is regulated by the rule of the Fire Underwriters.

In having a place wired, it is always well to have the contractor use a size or two larger than the Fire Underwriters' rules call for, so that in case more current is desired, it can be safely taken from the original installation. The extra cost does not amount to much.

In having electric service put in, it is always well to see that the cut-out blocks and fuses are put in a convenient place, so that in case of an accident a fuse can be easily replaced. As a rule, contractors do not figure on putting in a main switch, but it is advisable to have this done, and also to have it placed in circuit before the current enters the meter. The particular advantage of this is that in case you go away for any length of time, the current is absolutely shut off from the meter and the rest of the house. As long as the meter is connected with the service, it is consuming a small amount of current; this usually amounts to about 30 to 40 cents a month. Another advantage of the switch is that if you wish to make any changes, you can open this main line switch, being absolutely certain of not being injured by an accidental short-circuit.

A "flush receptacle" should be used for a Cooper Hewitt lamp or for a negative examining box with several incandescent lamps. A fused knife switch on a slate base is the proper thing for the *x*-ray connection or for a large arc-lamp. The ordinary key receptacle for a single incandescent lamp may be used for small motors and for cabinets for voltaic and faradic treatment, for diagnostic illumination, and for cautery.

Extracts from the Regulations of the U. S. National Board of Fire Underwriters.

In all electric work, conductors, however well insulated, should always be treated as bare, to the end that under no conditions, existing or likely to exist, can a ground or short-circuit occur, and so that all leakage from conductor to conductor, or between conductor and ground, may be reduced to the minimum.

Every reasonable effort should be made to secure distribution centers located in easily accessible places, at which points the cut-outs and switches controlling the several branch circuits can be grouped for convenience and safety of operation. The load should be divided as evenly as possible among the branches, and all complicated and unnecessary wiring avoided.

Outside Work.

(*a*) Service wires must have an approved rubber insulating covering. Line wires other than services, must have an approved weather-proof or rubber insulating covering. All tie wires must have an insulation equal to that of the conductors they confine.

(*b*) Must be so placed that moisture cannot form a cross connection between them, not less than a foot apart, and not in contact with any substance other than their insulating supports. Wooden blocks to which insulators are attached must be covered over their entire surface with at least two coats of waterproof paint.

(*f*) Must be so spliced or joined as to be both mechanically and electrically secure without solder. The joints must then be soldered, to insure preservation, and covered with an insulation equal to that on the conductors.

All joints must be soldered, even if made with some form of patent splicing device. This ruling applies to joints and splices in all classes of wiring covered by these rules.

Inside Work.

Wires

(*a*) Must not be of smaller size than No. 14 B. & S. guage, except as allowed under Nos. 24 v and 45 b.

(*b*) Tie wires must have an insulation equal to that of the conductors they confine.

(*c*) Must be so spliced or joined as to be both mechanically and electrically secure without solder. The joints must then be soldered to insure preservation and covered with an insulation equal to that on the conductors.

Stranded wires must be soldered before being fastened under clamps or binding screws, and whether stranded or solid, when they have a conductivity greater than that of No. 8 B & S. guage, they must be soldered into lugs for all terminal connections.

(*d*) Must be separated from contact with walls, floors, timbers, or partitions, through which they may pass by non-combustible, non-absorptive, insulating tubes, such as glass or porcelain, except as provided in No. 24, u.

(*e*) Must be kept free from contact with gas, water, or other metallic piping, or any other conductors or conducting material which they may cross, by some continuous and firmly fixed non-conductor, creating a separation of at least one inch. Deviations from this rule may sometimes be allowed by special permission.

When one wire crosses another wire, the best and usual means of separating them is by means of a porcelain tube on one of them. The tube should be prevented from moving out of place, either by a cleat at each end or by taping it securely to the wire.

The same method may be adopted where wires pass close to iron pipes, beams, etc., or where the wires are above the pipes, as is generally the case, ample protection can frequently be secured by supporting the wires with a porcelain cleat placed as nearly above the pipe as possible.

(*f*) Must be so placed in wet places that an air-space will be left between conductors and pipes in crossing, and the former must be run in such a way that they cannot come in contact with the pipe accidentally. Wires should be run over, rather than under, pipes upon which moisture is likely to gather or which, by leaking, might cause trouble on a circuit.

SWITCHES, CUT-OUTS, CIRCUIT-BREAKERS, ETC.

(*a*) Must, unless otherwise provided be so arranged that the cut-outs will protect, and the opening of a switch or circuit-breaker will disconnect, all the wires; that is, in a two-wire system the two wires, and in a three-wire system the three wires, must be protected by the cut-out and disconnected by the operation of the switch or circuit-breaker.

(*b*) Must not be placed in the immediate vicinity of easily ignitible stuff, or where exposed to inflammable gases or dust or to flyings of combustible material.

RUBBER-COVERED WIRE.

(*a*) Copper for conductors must be thoroughly tinned.

INSULATION FOR VOLTAGES BETWEEN 0 AND 600.

(*b*) Must be of rubber or other approved substance, and of a thickness not less than that given in the following table:

B. & S. Gauge	Thickness.
18 to 16	$\frac{1}{32}$ inch.
15 to 8	$\frac{3}{64}$ "
7 to 2	$\frac{1}{16}$ "
1 to 0000	$\frac{5}{64}$ "

Circular Mils.	Thickness.
250,000 to 500,000	$\frac{3}{32}$ inch.
500,000 to 1,000,000	$\frac{7}{64}$ "
Over 1,000,000	$\frac{1}{8}$ "

Measurements of insulating wall are to be made at the thinnest portion of the dielectric.

(*c*) The completed covering must show an insulation resistance of at least 100 megohms per mile during thirty days' immersion in water at 70° F.[1]

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[1] The insulation resistance of a gutta-percha covered wire is tested by immersing a mile or some fraction of a mile of the insulated wire, except at its two ends, in acidulated water. The tank must be of highly insulating material. One pole of a

(*d*) Each foot of the completed covering must show a dielectric strength sufficient to resist, throughout five minutes, the application of an electromotive force of 3000 volts per $\frac{1}{64}$ inch thickness of insulation under the following conditions:

The source of alternating electromotive force shall be a transformer of at least one kilowatt capacity. The application of the electromotive force shall first be made at 4000 volts for five minutes, and then the voltage increased by steps of not over 3000 volts, each held for five minutes, until the rupture of the insulation occurs. The tests for dielectric strength shall be made on a sample of wire which has been immersed in water for seventy-two hours. One foot of the wire under test is to be submerged in a conducting liquid in a metal trough, one of the transformer terminals being connected to the copper of the wire and the other to the metal of the trough.

PROTECTING BRAID.

(*h*) All the above insulations must be protected by a substantial braided covering, properly saturated with a preservative compound. This covering must be sufficiently strong to withstand all the abrasion likely to be met with in practice, and sufficiently elastic to permit all wires smaller than No. 7 B. & S. gage to be bent around a cylinder with twice the diameter of the wire, without injury to the braid.

Fusing-points of Metals and Alloys.—*German silver*, used for rheostats, melts at about 1996° F.

Fuse wires to melt when heated by a current in excess of the one they are designed to carry are made of different alloys.

Fusible amalgam melts at 53° C., or about 127° F. It consists of mercury, 1 part, and Arcet's metal, 9 parts.

Wood's alloy melts at 68° C., or 154° F., and consists of lead, 2 parts; tin, 4 parts; bismuth, 7 or 8 parts; and cadmium, 1 or 2 parts.

Arcet's metal melts at 94° C., or 201° F., and consists of lead, 5 parts; tin, 3 parts; bismuth, 8 parts.

An alloy melting at 119° C., or 246° F., consists of tin, 4 parts; bismuth, 5 parts; lead, 1 part.

An alloy melting at 141° C., or 286° F., consists of tin, 1 part; bismuth, 1 part.

An alloy melting at 165° C., or 334° F., consists of tin, 2 parts; bismuth, 1 part; or tin, 3 parts; lead, 2 parts.

All these fusible alloys are remarkable from the fact that they melt at a much lower temperature than any of the separate ingredients. The melting-point of tin is 442° F.; that of bismuth is 497° F., and of lead, 612° F.

The melting-points of other metals and alloys used in electric instruments are: Zinc, 773° F.; brass, 1869° F.; silver, 1873° F.; copper, 1954° F.; iron (wrought iron or iron wire), 3286° F.; nickel, 2800° F.; platinum, 3286° F.

Solder consists of various alloys, the common tin-solder containing tin and lead in proportions of 2 parts of the former and from 1 to 6 of the latter, and is used for soldering coarse wires. Silver solder may be hard or soft, the former containing 1 part copper and 4 parts silver, and the latter 2 parts of silver and 1 part of brass wire. It is useful for soldering fine wires and other parts of electrotherapeutic apparatus.

The regular electric-light sockets and the lamps themselves or the plugs on the flexible cords leading to a movable lamp are so constructed

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battery with known electromotive force is attached to a metal plate which dips into the liquid. The other pole is attached to a galvanometer or an electrometer from which a connection is made with one end of the wire to be tested. The other end of the wire is outside of the conducting liquid, and is not in contact with any conductor. The strength of current indicated by the meter furnishes a measure of the insulation resistance.

that when they are in use, there are no oppositely charged surfaces exposed to accidental contact. No shock or short-circuit can therefore occur in ordinary use. When the lamp is removed, two charged surfaces are exposed: one, the metal cylinder into which the lamp screws, and the other, a metal spring which is raised or depressed by the key and in this way makes or breaks connection with a small metal surface in the base of the lamp. To test the wires and see if they are charged, the electrician will often moisten his finger-tip and press it against these two surfaces inside of an electric-light socket. If there is any current, it is felt quite sharply, and usually causes the hand to be drawn away by a reflex contraction. This takes place whether the key at that socket is turned on or not. If there is no current, it may mean that the dynamo has stopped or that there is an imperfect connection somewhere between the dynamo and the lamp-socket. Screwing the lamp itself into the socket and turning the key is a more agreeable way of testing for current if a lamp is available. But there is no danger from the use of the finger, and no muscular contraction results which will prevent the finger being withdrawn at will.

To locate the trouble in case there is no current try other outlets on the same circuit. If they have current, the defect is probably in the socket itself, either a faulty connection with the two wires or an imperfection in the metallic connections in the socket. The first is readily repaired by screwing the wires fast in position; but the latter defect generally necessitates the use of a new socket. If the trouble is not at the socket itself and there is no current at other outlets on the same circuit, see about the fuses at the point where this circuit leaves the mains. These may have burned out, and if so, they must be replaced by new ones. Or they may make an imperfect contact and should be screwed more firmly into place or changed for new and perfect ones. If the trouble is at or near the main switch by which the connection between the house wires and the street wires from the dynamo is made or broken, there will be no current anywhere in the house. The main switch may have been turned off, and simply turning it on may be all that is required. Or the fuses at this point may have burned out or may be defective. All the fuses and contacts along the line being found to be perfect, but the apparatus still receiving no current, a break-finder will be found invaluable. It consists of a 16-candle-power incandescent lamp in a portable socket, with two insulated wires which terminate in long metal points which are insulated except at their extremity. Beginning at the street mains, apply the two points to the bare ends of the mains or to the binding posts securing them. If there is any current there, the lamp will light up. If not, the electric-light company should be notified. If there is current in the street mains, turn the main switch on and test the two bare ends of the house mains at the point where they are secured by the binding posts of the main switch. Finding no current there, it will be a simple matter to remedy the defective contact which this indicates at the main switch. If there is current there, the next place to be tested is the other end of the house mains. The bare wires are to be touched by the two points of the break-finder, and if no current is obtained, it means a break in one of the main wires between this point and the main switch. This is very unlikely to occur if unbroken lengths of wire are used for these mains; but if there has been a joint in either wire, it should be exposed and will usually be found to be the seat of trouble. The two ends of the wire at this joint should be scraped bright and clean of oxid, and should be twisted together and soldered. The next place to be tested is the beginning of the circuit in which the current is lacking. Apply the break-finder to the two bare ends of these wires, and if there is no current there, the trouble lies in some of the connections right at this point where the current passes from the house mains through a fuse to the distributing circuit. Trouble here can usually be remedied quite easily by tightening screws or putting in a new fuse. Finding current in the ends of the distributing circuit at this point, investigate the ends of these wires where they are fastened to the socket or knife switch for the apparatus. If no current is found there, the trouble is due to a break in one of these wires. They should have been single lengths of wire, and if they were not, the imperfect connection should be sought at the joint which may not have been soldered. Finding current in the wires at the socket or knife switch and none in the apparatus, the break-finder may be applied to the contact surfaces at which the current should enter the lamp-base or the wires of the apparatus. The absence of current there indicates an imperfect connection in the socket or switch, and this is sometimes remedied by tightening a screw or bending a spring into better position, but it often indicates the necessity for a new socket.

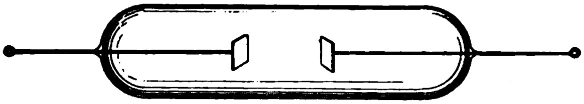


Fig. 157.—Pole detector.

A pole detector (Figs. 157 and 158) makes a very convenient break-finder for any part of the electrotherapeutic apparatus itself. It will show the presence as well as the direction of any current from 1 to 500 volts. Connecting the two ends with two oppositely charged wires, the passage of the current produces a chemic change in the liquid, resulting in a red cloud around the negative electrode. Its advantage over a lamp is that it is sensitive enough for the weakest therapeutic currents and will indicate without injury the strongest currents ever applied to medical apparatus. No other apparatus covers so wide a range without requiring adjustment. It is not suitable for the detection of the secondary currents of exceedingly high potential and great amperage which are produced by x-ray coils, but it is not required for these currents, as they manifest themselves in a striking manner if present.

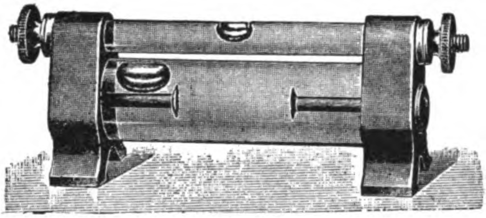


Fig. 158.—Pole detector.

Pole Detector.—The formula for the liquid is: 50 grams glycerin; 3 grams saltpeter; 20 grams water; 0.5 gram phenolphthalein; previously dissolved in 10 grams alcohol. Pole connected with negative wire turns violet.

Insulating Materials.—*Insulating Varnishes.*—*For Wood.*—Sealing-wax dissolved in alcohol and painted on in four or five thin layers.

For Galvanometer Coils.—Gum copal dissolved in ether and painted over each layer.

Shellac Varnish.—One ounce of shellac to eight ounces naphtha or wood alcohol. This dissolves slowly, and should be filtered, adding more liquid and changing the filters to facilitate that process.

For silk use six ounces of boiled linseed oil and two ounces of spirits of turpentine.

For Large Coils.—Cotton-covered wires are soaked in melted paraffin. Large electromagnet coils have a double layer of cotton thread, and the outer layer is coated with a thick varnish of shellac.

Insulating Paper.—Absorbent tissue-paper is rendered insulating by soaking in melted paraffin, and is then suitable for use as the dielectric in the large condensers used in telegraphy and in connection with faradic coils. Heavier paper, 0.011 inch thick, varnished with one part Canada balsam and two parts spirits of turpentine, is required for the condenser of an *x*-ray coil. Two layers of this paper are required in the most powerful coils between the layers of tin-foil. These two thicknesses of varnished paper are about as thick as five leaves in this book.

Insulating tape is prepared by soaking in Stockholm pitch, 8 parts, wax, 2 parts, tallow, 1 part.

Wood is rendered insulating by boiling it in melted paraffin until bubbles of air cease to rise, or by painting it with melted paraffin.

Wood is rendered both insulating and unaffected by acids if thoroughly coated with Burgundy pitch, 1500 grams; old gutta-percha in shreds, 250 grams; powdered pumice, 750 grams. Melt the gutta-percha, mix with the pumice, and add the pitch. An oak trough coated with this preparation will serve for years as a jar for a voltaic or a storage battery or for an electric bath. The same preparation will protect a metal tank used for similar purposes from the action of acids, but the insulation should be supplemented by placing the tank on an insulated support (wood treated in the same way, or glass), and by preventing direct contact between the tank and any of the metallic wires or electrodes.

Acid-proof insulating cement is made by melting 1 part of rubber with 2 of linseed oil and then adding 2 parts of pipe-clay.

Chatterton's compound contains Stockholm pitch, 1 part; resin, 1 part; and gutta-percha, 3 parts. It is used for joining the layers of gutta-percha in the insulated covering of wires and cables.

The *dielectric rigidity*, or the voltage required to discharge through 1 mm. of air, is 4000; of mica, 61,000; of hard rubber, 55,000, and of resin oil, 20,000. But to have such great insulating power the oil must be entirely free from water and acids.

Tapping a Line for an Additional Outlet.—It will often happen that one or more outlets are desired from a pair of 110-volt wires besides the outlet in which the wires terminate. This can usually be done without disturbing the wires except at the point where they are to be tapped. For instance, if the wires are laid in molding, the capping is removed and the wires lifted out of the wooden groves for a few inches. The current should have been shut off at the main switch, and if there is a possibility of this being turned on by some one else, the fuse plugs of this particular line had better be removed. It would be absolutely wrong to handle bare live wires with metallic instruments. Each wire is tapped separately. The insulating cover is stripped from the wire for about an inch, and the wire is scraped free of oxid. The end of the wire that is to be fastened to this has been similarly prepared and is wrapped several times around the line wire. The joint should certainly be soldered, and this is done by first painting it over with a *soldering fluid,* such as: Saturated solution of zinc chlorid, 5 parts; alcohol, 4 parts; glycerin, 1 part, and then melting a small amount of solder over the turns of wire. All the bare wire should be covered with several layers of insulating tape, and the wire pressed back into the wooden groove. The other wire having been tapped in the same way, but at a distance of about an inch from the level of the first, the capping of the molding is nailed down in position again. The two side wires should not be flexible wires leading directly to any apparatus, but should be inclosed in molding and lead to a stationary switch-board or receptacle. At the place where the line is tapped the side wire from one of the line wires has to pass over the other line, and in doing so it should be outside of the wood capping. It is often desirable to apply a short length of flexible loom or of porcelain tubing covering one wire where it crosses the other.

The 110-volt alternating current is supplied in the same way by a three-wire system. It is a current which produces a much more marked physiologic effect than the direct current, and so the wires should be handled more carefully. While the cautious use of the finger is permissible as a means of testing the presence or absence of current, still it will be found less disagreeable to use a lamp, a break-finder, or a pole detector for this purpose. Such a current will not flash across any greater space than the 110-volt direct current, and requires exactly the same sort of wiring. It may be used directly for running motors of special construction, for diagnostic and therapeutic lamps, and for electric baths. Its tension is regulated by a volt controller, and its intensity or amperage by a choke or inductance coil. It may be made available for *x*-ray and high-frequency currents by means of a rotary transformer or electrolytic rectifier and suitable accessory apparatus, as in the d'Arsonval-Gaiffe or the Snooks or Kny-Scheerer outfit. It is not directly available for most forms of electrotherapy, and especially not for electrodiagnosis where a polar effect is often essential, but it may be used to run a motor generator from which a suitable current with a fixed polarity may be obtained. It may also be used to run a motor transformer yielding a sinusoidal current, which has very marked therapeutic properties.

The intensity of an alternating current may be measured by means of a hot wire milliamperemeter. The current or a shunted portion of the current passes through a wire whose increase in length under the influence of heat causes a corresponding motion of the indicator. The instrument is graduated by experimental comparison with a standard instrument. The wire is heated by a series of currents in alternating directions, very much as it would be by a series of currents in the same direction. The voltmeter for alternating currents must also be a hot-wire instrument. Taking the number of volts and of amperes indicated by the two instruments and multiplying these together to obtain the indicated number of watts produced by the dynamo, it will often be found to exceed the amount of power expended in running the dynamo. The hot wire milliamperemeter evidently does not register the average strength of the currents passing through it in alternate directions, but indicates somewhat more than the true figure. The repeated surges of heat produced by the maximum current are more effective than the tendency on the part of the wire to cool during the instants when the current is zero.

Trolley-car Currents.—The 500- or 550-volt direct current of the trolley-car system used for electric arc-lamps in the street and public places is of such high potential that it will leap across a considerable distance and has a very dangerous effect upon living creatures. Death may result from the current passing through the body by accidental contact with two oppositely charged bare wires, or with one bare wire and some good ground connection. The person may escape with only a severe shock and burn if he is in a partially insulated position and touches only one wire. The wires are not only a direct danger, but an indirect one, for other wires, telephone or telegraph, may fall across them and shock or kill human beings. Horses are said to be more apt than men to be killed, and it may be because their iron shoes form a good ground connection. An insulated body when brought near to or in contact with a charged body acts only to a slight extent as a conductor, but for the most part as a capacity. It acts like a container into which a certain amount of liquid is poured, and not like a section of pipe of the same size through which a continuous stream is poured, perhaps ten times its cubic capacity passing through the section of pipe in a second. A short length of fine wire suspended by a silk thread may be swung into contact with a bare wire charged with electricity at a voltage of 550, and will be found to have received a charge of electricity, but only a very slight one as compared with what it would receive from contact with the prime conductor of a static machine. The wire undergoes no appreciable change, and if swung away from the 550-volt conductor and against one's hand, its electric charge will be hardly perceptible. But the same fine wire will be heated and fused or even vaporized if it crosses two oppositely charged wires with a 550-volt potential, or if it forms a conducting path between one of these and the earth. Insulating the human body and then touching a bare 550-volt conductor is not to be recommended as an experiment: it is only referred to at this place to show the direction of safety and of danger in the management of such a current.

A 550-volt current is entirely unsuited to any electrotherapeutic application. It must be changed to a current of a much lower potential. and this cannot be economically done by a volt controller. This would involve a great waste of power, sending three-quarters of the current through a parallel and unused path, and also producing an amount of heat in the side conducting path which would require special arrangements to guard against fire. The same overheating would occur if reliance were placed upon a rheostat. Unless the electric company is willing to do so, it will be necessary for the physician to have a motor generator or a transformer to produce the desired current—110 volts or less. The motor generator is the proper apparatus for use with the direct current. It is a motor actuated by the 550-volt current, and running a dynamo which may be constructed to generate a current of any desired voltage, either direct, alternating, sinusoidal, or polyphase. The closed magnetic ring transformer converts the power of a 550-volt alternating current into an alternating current of any other desired voltage by a process of induction which takes place between two stationary coils. The rotary transformer is for the same purpose in connection with the direct current, but looks like a dynamo or motor generator, and in it the charged coils of wire are rapidly rotated. The ease with which the alternating current can be changed in voltage by a transformer without any movable parts and without any sparks or bare charged wires makes it very convenient commercially. There is a wonderful economy in the weight of copper wire for the long-distance transmission of power as an electric current of very high voltage—10,000 or 15,000 volts. The same amount of power as a current of 500 volts would have 20 or 30 times the amperage, and would require 400 or 900 times as great a conducting path. According to Joule's law, the amount of heat disengaged in a given time is directly proportional to the square of the strength of the current and to the resistance. The strength of the current means the number of amperes or milliamperes. It will readily be seen that the higher voltages are an absolute necessity when it comes to a matter of transmitting thousands of horse-power as an electric current. These tremendous voltages, of course, need the *heaviest* kind of insulation wherever they touch any solid support, and require that the conductors should not be on the surface of the ground, and that they should be far enough apart from each other or from other metallic conductors to prevent the current from leaping across the air-space which forms the insulation. Accidental contact of human beings with the metallic conductors should be most effectually guarded against, as it would certainly be fatal. Currents of such tremendous voltage are always modified by a step-down transformer before entering the power-house, where they are further acted upon by rotary converters and changed into a direct current of 550 volts for the trolley line, and of other voltages for charging storage batteries and for electric lighting. Almost any bare wire or binding-post in such a power-house is charged with a current which would make accidental contact extremely dangerous. There is also a great amount of electromagnetic and electrostatic induction in the room at the power-house where these high voltages and rapid alternations are present, and two special effects are produced. One is a *magnetizing effect* upon watches, causing them to run irregularly, and another is an effect upon the *nervous system* of the operatives, producing symptoms of neurasthenia. The air of the room is kept warm by the conversion into heat of a certain portion of the electric current passing through the various portions of the apparatus.

The best conductors are those which transmit an electric current with the least ohmic or, in other words, frictional resistance, but there is always some resistance, and in the case we are considering the resistance is not only a measurable but a large quantity. The electricity lost by ohmic resistance is converted into heat. Special attention is always paid to arrangements for the dissipation into the air of the heat produced by ohmic resistance in the wires forming part of dynamos and motors. A rise of 50° F. in the temperature of the apparatus is regarded as the limit of safety. The hotter a body becomes as compared with the surrounding atmosphere, the more rapid becomes the dissipation of the heat. In an apparatus through which the same amount of electricity passes every minute and in which, consequently, the same amount of heat is generated every minute, the maximum temperature attained is the temperature at which the rate of dissipation of heat becomes equal to the rate of heat-production. The room in which all these great dynamos are in operation is so warm that no artificial heat is required, and the doors and windows are left open.

The great copper bars forming the ground connection or return circuit from the trolley-car rails to the dynamo carry a tremendous amperage, but a very low voltage. These can be touched with the bare hand, and are found to feel quite warm from the friction of the electric current passing through them. One of these bars carries a current sufficient to kill 100 men, but at so low a pressure or voltage that the amount which will pass through the human body is not sufficient to produce a perceptible sensation. This amount is found by dividing the voltage by the number of ohms resistance in the body, and is not exceeded no matter what may be the size and amperage of the generator.

Either the 550-volt current of the trolley-car circuit or the 10,000- or 15,000-volt current for long-distance transmission of power passes through a continuous insulated conductor of ample size, with just as little evidence of its existence as the 110-volt current passing through the flexible cord to an incandescent lamp upon a writing desk. And just as a short-circuit of the 110-volt current will cause heat enough to vaporize a steel knife-blade, these other currents with heavier voltages and greater amperages cause destructive conflagrations when short-circuited. Automatic circuit-breakers are always employed, breaking the circuit the moment that an excessive current begins to flow through the line.

A *circuit-breaker* is like a knife-switch, which is thrown wide open by the action of an electromagnet which is not strong enough to throw open the switch with any ordinary current, but becomes so under the influence of an abnormally strong current.

A common use of the circuit breaker is in an automatic cut-off arranged to break the circuit in case of an excessive flow of current. A powerful spring tends at all times to press the control lever over to "off," or the position of no current. When this lever is pressed over to the place of maximum current flow it is held there by a powerful electromagnet. Forming a part of the same apparatus is another electromagnet which tends constantly to actuate a circuit breaker, but is opposed by a spring which may be set so that it will yield to more than a definite strength of current. An excessive current causes the circuit breaker to act; the electromagnet loses its power to hold the resistance lever, and the latter springs back through the positions of greater and greater resistance to that of no current. This is part of the equipment of any powerful x-ray generator.

The induced currents produced for therapeutic application by a faradic coil are of a higher voltage, and correspondingly lower amperage than the primary current. The faradic current will, therefore, overcome the resistance of the dry skin, and two dry uncovered metal handles held in the hands will transmit a current through the 1000 ohms resistance of the body. A voltaic current of the usual voltage would not be transmitted in any effective amount under the same conditions. The faradic current is usually an alternating and an interrupted one, and each impulse varies in voltage from a maximum to a minimum. Methods of measurement of the voltage are by the use of a faradimeter or of an electrostatic voltmeter. The latter depends upon the attraction between two oppositely charged bodies, while the faradimeter is composed of two coils between whose ends a bundle of soft-iron wire or a coil of wire is freely suspended. The soft-iron core tends to assume a position parallel with the long axis of the coils, and indicates upon a dial the strength of the current passing through the coils. The strength of the current is, of course, dependent upon the voltage. Either of these appliances probably gives an approximation to the maximum voltage and not the average voltage. Measurements have been made which indicate that the potential of a faradic current, while actually being applied to a human being, is about 10 volts, while other measurements indicate that the difference in potential between the two poles on open circuit is about 90 volts. As it takes a voltage of 10,000 to 30,000 to spark across an air-space of an inch, the spark to be obtained from 10 volts would be only $\frac{1}{1000}$ or $\frac{1}{3000}$ inch long, and that from 90 volts about $\frac{1}{100}$ or $\frac{1}{300}$ inch long. And this is about the result obtained when the two bare ends of the wires from a faradic coil are brought together; it is difficult to get any spark at all except by rubbing the ends over each other and securing an imperfect contact. It is hardly possible to hold the ends at any distance apart and secure a continuous stream of sparks. With the strongest therapeutic faradic current the sparks that can be obtained are little bright points without noise and without any effect upon the metal points. The amperage is very small indeed. As in the case of the voltaic current for medical purposes, the wires carrying the faradic current require nothing but the thinnest complete layer of insulating material.

The Centimeter-gram-second System of Electric Units.—The centimeter is the metric unit of length, and is equal to 0.3739 inch. The *gram* is the unit of weight in the same system, and is the weight of a cubic centimeter of water at 4° C., the temperature at which water has its maximum density. The *second* is the unit of time in the same system.

Force is that which produces motion or change of motion in a body. The *dyne* is the C. G. S. unit of force, and acting for one second upon a body weighing one gram, it will give the body a velocity of one centimeter per second. *Work* is the product of a force by the distance through which it acts. The C. G. S. unit of work is the *erg*, or the work done in overcoming a force of one dyne through a distance of one centimeter. A concrete example of work is the raising of a body weighing one gram to a height of one centimeter. Since the attraction of gravity acting on a mass of one gram for one second will give a velocity of 981 centimeters per second, the force exerted by gravity upon a body weighing one gram is 981 dynes. Therefore, the work done in raising a mass of one gram to a height of one centimeter is 981 ergs. Other units of work are the kilogram-meter $= 100{,}000 \times 981$ ergs, and the foot-pound $= 1.356 \times 10^7$ ergs $= 13.56$ million ergs.

Kinetic energy is the work which a body can do by virtue of its motion. *Potential energy* is the work which a body can do by virtue of its position. The unit in either case is the erg.

The unit of the rate of work is one erg per second. A *horse-power* $= 33{,}000$ foot-pounds per minute is 7460 million ergs per second. The horse-power represented by an electric current is equivalent to the electric energy of $\frac{EC}{746}$ or $\frac{C^2R}{746}$ or $\frac{E^2}{746R}$, in which expression $E =$ volts, $C =$ amperes, and $R =$ ohms.

One *horse-power* is $\frac{3}{4}$ kilowatt or 746 watts. One *kilowatt* is 1.34 horse-power.

Electric units are derived from the centimeter-gram-second system.

There are two sets of them—the electrostatic and the electromagnetic systems. The electrostatic system has for its unit of quantity the amount of electricity which will exert a force of one dyne upon a similar quantity of electricity at a distance of one centimeter. The force will be one of attraction if one charge is positive and the other negative; and of repulsion if both are of the same sign (+ or −). The electrostatic units of current, electromotive force, and capacity are derived from this unit of quantity.

The electromagnetic system of C. G. S. units is the one that is commonly in use, and is based upon the force exerted between two magnetic poles. For instance, a *unit magnetic pole* repels a similar pole at a distance of one centimeter with a force of one dyne. The C. G. S. unit of *current* is a current which, passing through a wire one centimeter long, bent into an arc of a circle whose radius is one centimeter, will exert a force of one dyne upon a unit magnetic pole situated at the center of the circle. The C. G. S. unit of *quantity* is the amount of electricity transferred in a second by a current of a strength of one unit. The C. G. S. unit of *electromotive* force is that which must be maintained between the ends of a conductor in order that a current of unit strength shall do one C. G. S. unit of work in a second. The C. G. S. unit of *resistance* is that of a conductor in which a unit of current is produced by a unit of electromotive force. The C. G. S. unit of capacity is the capacity of a condenser which will be at a potential of one unit of electromotive force when charged with one unit of quantity.

Practical Units of Electricity.—The electric units in every-day use are arbitrarily selected, and are of a size to be readily measured, so that the currents ordinarily employed can be represented by only a few units. The comparison between the ohm, for instance, and the C. G. S. unit of resistance is about like that between the ton and the grain as units of weight.

The *coulomb* is $\frac{1}{10}$ C. G. S. unit of electric quantity, or 10^{-1} C. G. S. units. It decomposes 0.0000945 gram of water or deposits 1.118 milligram of silver. It is the amount of electricity transferred in a second by a current of one ampere.

The *ampere* is the unit of current or of the rate of flow of electricity. A current of one ampere transfers one coulomb of electricity per second. It decomposes 0.0000945 gram of water per second. It is equal to $\frac{1}{10}$ C. G. S. unit of current.

The *milliampere* is one-thousandth of an ampere.

The *volt* is the practical unit of electromotive force, and is the electromotive force which will maintain a current of one ampere through a resistance of one ohm. It is equal to 10^8 C. G. S. units of electromotive force, and is about 7 per cent. less than the electromotive force of a Daniell cell.

The *ohm* is the practical unit of resistance, and is equal to 10^9 C. G. S. units of resistance. It has been defined by international agreement as the resistance of a column of mercury 106 centimeters long, one square millimeter in cross-section, and at a temperature of 0° C. or 32° F.

The *farad* is the practical unit of capacity, and is equal to 10^9 C. G. S. units of capacity. It is such a capacity that a coulomb will charge it to a potential of one volt.

The *microfarad* is one-millionth of a farad. A Leyden jar with a total coated surface of one square yard would have a capacity of about $\frac{1}{38}$ microfarad.

The *watt* is the practical unit of electric power, and is equal to 10^7 C. G. S. units of power. It is the power conveyed by a current of one ampere through a conductor whose resistance is one ohm, and which consequently requires an electromotive force of one volt. It is equal to one joule per second, or $\frac{1}{746}$ horse-power. The number of watts is equal to the number of amperes multiplied by the number of volts—$W = CE$. Or, it is equal to the square of the current strength in amperes multiplied by the resistance in ohms—$W = C^2R$. Or it is equal to the square of the electromotive force in volts divided by the resistance in ohms—$W = \frac{E^2}{R}$.

The *kilowatt* is 1000 watts, and may, for example, indicate a current of 10 amperes at a 100 volts, or a current of 5 amperes at a 200 volts. It is one of the standard units of electric power.

The *kilowatt-hour*, equal to 1000 watts acting during one hour, is a standard electric unit of work, and is the unit upon which the electric-light companies base their charge for the use of the current. It may, for example, indicate the work done in an hour by a current of 10 amperes and 100 volts. A current greater than one kilowatt acting for a correspondingly shorter time or a smaller current for a longer time may constitute a kilowatt-hour. A kilowatt-hour is equal to 1.34 horse-power working for one hour. One horse-power (h. p.) = 33,000 foot-pounds per minute.

The *joule* is the practical unit of heat or work upon which the mechanic equivalent of heat is based. It is the work done or the heat generated in a second by a current of one ampere passing through a resistance of one ohm. It is the amount of heat equivalent to 10^7 C. G. S. units of work. It is found to be the amount of heat necessary to raise 0.2405 gram of water one degree Centigrade.

The *calorie* is the French unit of heat, and is the amount of heat required to raise the temperature of 1 gram of water 1° C. It is analogous to the English heat unit, the pound-degree.

The *heat* generated in a wire by a current of electricity in a certain length of time is found by a formula in which C is the current strength in amperes; R, the resistance in ohms; E, the electromotive force in volts, and T, the time in seconds. The heat generated in the time T; $= C^2RT \times 0.2405$ calories (gram degrees), or, it is equal to $ECT \times 0.2405$ calories. Thus, a current of 1 ampere and 100 volts will in one second generate 24.05 calories, or heat enough to raise the temperature of 1 gram of water 24.05° C. Written out in full: The number of calories (gram degrees) generated by an electric current in a certain number of seconds is equal to the square of the number of amperes, multiplied by the number of ohms, by the number of seconds, and by 0.2405. Or, again, the number of calories generated in a certain number of seconds is equal to the number of volts multiplied by the number of amperes, by the number of seconds, and by 0.2405.

The Different Wire Gauges.—The one usually referred to in America when the size of a wire is spoken of as such a number is the Brown and Sharpe wire gauge (B. S. G.). For example, the No. 36 wire so generally employed for the secondary coils in faradic or *x*-ray apparatus is No. 36 B. and S. The other gauges are British Standard Gauge (S. W. G.); the Birmingham Wire Gauge (B. W. G.); and the French Wire Gauge (F. W. G.). In addition to these gauges in which wire is referred to by number, the size of a wire may be designated by stating its diameter in fractions of an inch or in millimeters.

No. 36 (B. and S.) is 0.005 inch, or 0.1 millimeter in diameter. Its equivalents are No. 40 (S. W. G.) and No. 35 (B. W. G.). It is used for the secondary of induction coils.

No. 22 (B. and S.) is 0.0253 inch or 0.6 millimeter in diameter. Its equivalents are No. 23 (S. W. G.), No. 23 (B. W. G.) and No. 1 (F. W. G.). It is used in the primary winding of induction coils.

No. 14 (B. and S.) is 0.0641 inch or 1.6 millimeters in diameter. Its equivalents are No. 16 (S. W. G.), No. 16 (B. W. G.), and No. 11 (F. W. G.). It is used for the house-wiring, passing from the mains to individual electric-light sockets.

No. 10 (B. and S.) is 0.1019 inch or 2.7 millimeters in diameter. Its equivalents are No. 12 (S. W. G.), No. 12 (B. W. G.), and No. 16 (F. W. G.). It is a suitable size for the house-wiring leading from the mains to the switch-board for an *x*-ray coil or to an arc-light. It is heavy enough even for the mains for an electrotherapeutic installation, provided that not more than about 25 amperes of current in the various apparatus are ever to be turned on at the same time.

No. 8 (B. and S.) is 0.1285 inch, or 3.4 millimeters in diameter. Its equivalents are No. 10 (S. W. G.), No. 10 (B. W. G.), and No. 18 (F. W. G.). It is suitable for the mains for a complete electrotherapeutic installation, including *x*-ray, arc-light, and electric-light baths, but not to exceed 100 amperes at any one time.

EQUIVALENTS OF B. & S. WIRE GAUGE IN DECIMAL PARTS OF AN INCH.

Number of Wire Gauge.	Diameter in Inches.	Number of Wire Gauge.	Diameter in Inches.
000000	....	18	0.040303
00000	....	19	0.035890
0000	0.460000	20	0.031961
000	0.409640	21	0.028462
00	0.364800	22	0.025347
0	0.324860	23	0.022571
1	0.289300	24	0.020100
2	0.257630	25	0.017900
3	0.229420	26	0.015940
4	0.204310	27	0.014195
5	0.181940	28	0.012641
6	0.162020	29	0.011257
7	0.144280	30	0.010025
8	0.128490	31	0.008928
9	0.114430	32	0.007950
10	0.101890	33	0.007080
11	0.090742	34	0.006304
12	0.080808	35	0.005614
13	0.071961	36	0.005000
14	0.064084	37	0.004453
15	0.057068	38	0.003965
16	0.050820	39	0.003531
17	0.045257	40	0.003144

Conductivity of Metal Wires.—The specific conductivity of pure silver wire is taken as 100, that of pure copper wire is 80, and the conductivity of copper wire suitable for electric work, 95 per cent. that of pure copper. The specific conductivity of silver is 100; copper, 80; gold, 55; zinc, 27; tin, 17; iron, 14; palladium, 12.5; platinum, 10.5; lead, 7.8; antimony, 4.3; mercury, 1.6; bismuth. 1.2. This means that under identical conditions as to voltage and size and length of wire the strength of current transmitted will be in the proportion indicated by the specific conductivities.

Units of Resistance.—In the C. G. S. system the unit of resistance is that of a pure copper wire one millimeter in diameter and $\frac{1}{20,000}$ millimeter long.

In the system commonly employed the unit of resistance is the ohm, which is equal to the resistance of a pure copper wire one millimeter in diameter and 48.64 meters long.

The Specific Resistance of Metal Wires.—The specific resistance of pure copper, or the resistance of a cubic centimeter at 0° C. is 0.000001642 ohm. The specific resistance of the various other metals is a matter of simple calculation based upon a comparison of their conductivity with that of copper. For instance, platinum has about one-eighth the specific conductivity of copper, and has, therefore, about 8 times the specific resistance. A pure copper wire 1 square centimeter in cross-section and 1 centimeter long has a resistance of 0.000001642 ohm, and 100,000 times that length, or a kilometer (equal to 3280.9 feet) of the same wire would have a resistance 0.1642, or about $\frac{1}{6}$ ohm.

TABLE OF THE RESISTANCE OF DIFFERENT METAL WIRES.

Name of Metal.	Approximate Comparative Resistance.	Resistance of a Wire 1 Meter Long and 1 Millimeter in Diameter.
Silver	1.00	0.01937 ohm
Copper	1.06	0.02057 "
Gold	1.38	0.02650 "
Aluminum	1.94	0.03751 "
Platinum	6.08	0.11660 "
Iron	6.80	0.12510 "
Lead	13.60	0.25260 "
Mercury, liquid	62.50	1.22470 "
German-silver (copper, 4; nickel, 2; zinc, 1, parts)	7.22	0.13990 "

The resistance of any length of wire of any diameter may be calculated from this table. Multiply the resistance of one meter, as given above, by the number of meters, and divide by the square of the diameter expressed in millimeters. Thus the resistance of a copper wire $\frac{1}{10}$ millimeter in diameter and 100,000 meters long would be found by the following equation:

$$R = \frac{0.02057 \times 100,000}{\frac{1}{10}^2 \text{ (or } \frac{1}{100})} = 205,700 \text{ ohms.}$$

This is the size, No. 36, B. W. G., and length of the secondary wire in some 16-inch induction coils. The 200,000 ohms resistance is what might be termed the frictional resistance, and causes loss of power by converting a certain amount of the electric energy into heat. The other impedence to the flow of the current is inductance, and is dependent on the number and arrangement of the number of turns, not on the length and thickness of the wire. It is not under consideration at this place.

German-silver wire is frequently used for rheostats and other resistances, and the foregoing table enables one to calculate the resistance of a certain length of wire of a certain diameter. The following table will also be found of value.

RESISTANCE OF 36 INCHES OF GERMAN-SILVER WIRE AT 60° F.

B. W. G.	Diameter.		Resistance, Ohms.
	Inch.	Millimeters.	
No. 10	0.136	3.454	0.02425
" 14¼	0.080	2.032	0.07000
" 20	0.036	0.914	0.34800
" 24	0.022	0.558	0.93100
" 30	0.012	0.305	3.23000
" 36	0.004	0.106	28.17500

Silicious bronze has almost the conductivity of copper, *i. e*, 7 times less resistance than iron, and bronze wires weighing 100 pounds to the mile can be substituted for iron wires with great economy in cost and an increase in conductivity.

Filling a Bobbin to a Certain Resistance.—If the outer diameter of the coil of wire is to be A, and the inner diameter a, and its length b, the resistance required is R, and i is the radial thickness of the insulated wrapping of the wire. The diameter d of the wire which will fill such a bobbin and produce the required resistance is found by the equation $d = -i + i^2 + \frac{\mathrm{kb}(\mathrm{A}^2 - \mathrm{a})}{\mathrm{R}}$, where k is the resistance of a wire $\frac{3.1416}{4}$, or $\frac{3.14}{4}$, units long and 1 unit in diameter (Brough).

The *length of wire required to fill a coil* is found by the equation $\mathrm{L} = \frac{3.1416\mathrm{b}}{4\,\mathrm{d}^2}(\mathrm{A}^2 - \mathrm{a}^2)$, and here d is the full diameter of the wire, including its insulation. Or another formula is: add the thickness of the coils to the diameter of the core outside of its insulation, multiply by 3.14, again by the length, and again by the thickness of the coils $(\mathrm{A}-\mathrm{a})$, and divide by the square of the diameter of the wire.

The *number of turns of wire in a coil* is found by multiplying the thickness of the coil $(\mathrm{A}-\mathrm{a}$ of the previous paragraphs) by its length and dividing by the square of the diameter of the wire.

The *total weight or resistance* is easily found from one of the printed tables if the length and diameter of the wire are known.

Effect of Temperature upon Resistance.—This has to be taken into account in some of the commercial uses of electricity, but it is so small that it may be disregarded or only approximately calculated in electrotherapeutics. The resistance of a copper wire increases about one-fifth of 1 per cent. for each degree F., or $\frac{38}{100}$ of 1 per cent. for each degree C. that the temperature rises. A German-silver wire shows an increased resistance of only one-twentieth of 1 per cent. for each degree C. that the temperature rises.

The Production of Heat in Conducting Wires.—The ohmic resistance of a conducting wire is a measure of the power which would be required to simply make the current flow through the wire if the wire were straight and uninfluenced by any other object. This portion of the power from the generator corresponds to the power lost by friction in ordinary machinery. None of the electric power so consumed is active in inducing other currents or in causing mechanic motion. It is converted into heat. The heat produced in this way varies directly as the resistance and as the square of the current or amperage. The power wasted in simply overcoming what may be considered the frictional resistance to the passage of the current through the wire also varies directly as the resistance and the square of the amperage.

The following formula enables one to calculate the number of horsepower wasted in the form of heat by the passage of a current of electricity through a wire:

$$HP = \frac{C^2R}{746} = C^2R \times 0.00134.$$

The actual amount of heat generated in a given time, T, is equal to $C^2RT \times 0.2405$ (gram-degrees). In this formula C^2 is the square of the number of amperes, R the number of ohms resistance, and T, the number of seconds that the current flows. The product of these three factors is to be multiplied by 0.2405 to find the number of gram-degrees or calories. One calorie is the heat required to raise the temperature of one gram of water one degree C.

The Rise of Temperature in a Conducting Wire.—This will depend partly on the amount of heat generated in it in a given time, and partly on the rate at which this heat escapes from the wire. The larger the wire, the less will be its resistance and the less heat will be generated in it, but there is always some. Insulated wire for the mains and the separate circuits of house-wiring should be of such a size that its temperature will not rise more than 25° or 30° F., no matter how long the current flows. A good empirical rule is that a copper conductor 2 inches in diameter will safely carry a current of 2000 amperes, and that the safe carrying capacity of wires of greater or less diameter varies as the square root of the third power of the diameter. An example of the application of this rule would be in finding the safe carrying capacity of a No. 14 B. W. G. wire, which is about 0.08 inch in diameter. Calling the unknown carrying capacity *X*—

$$\sqrt{2^3} : \sqrt{0.08^3} :: 2000 : X.$$

$$\sqrt{2^3}\,X = \sqrt{0.08^3}\,2000.$$

$$X = \frac{\sqrt{0.08^3}\,2000}{\sqrt{2^3}} = \frac{2000 \times 0.02263}{2.83} = 16.$$

A No. 14 copper wire will accordingly carry a 16-ampere current without overheating.

LENGTH, WEIGHT, AND RESISTANCE OF COPPER WIRE.

B. W. G.	Weight and Length, Pounds per Mile.	Length and Resistance, Ohms per Mile.	Resistance and Weight. Ohms per Pound.	Pounds per Ohm.
8	435.00	2.00	0.00460	217.343000
10	287.00	3.03	0.01058	94.543000
14	189.90	4.59	0.02416	41.392000
20	19.60	44.49	2.27254	0.440000
24	7.80	112.62	14.55790	0.069000
30	2.30	378.51	164.46500	0.006000
36	0.25	3406.60	13200.00000	0.000075

The Heating of Coils of Wire by a Current.—The heat developed in closely wound coils of wire, as in dynamos and *x*-ray coils, finds a comparatively small radiating surface, practically only the outer surface of the outermost layer, and a greater rise of temperature will result. A rise of 50° C. is considered safe for the wires in the electromagnets of a dynamo. Generally speaking, wires are considered to be overheated when they are too hot for the hand to be kept upon them for a minute at a time without discomfort. Bobbins of the same size when wound with wires of different calibers contain a length of wire which is inversely proportional to the square of the diameter of the wire. The resistance in such bobbins is inversely proportional to the fourth power of the diameter of the wire. To secure equal heating in the two bobbins the current strength in amperes divided by the square of the diameter of the wire should give the same number in both.

The safety limits are those within which there is no danger of injuring the insulation of the wires in the coils. Coils in which the wire is 2 millimeters in diameter can safely carry about 15 amperes; and with wire 5 millimeters in diameter, about 60 amperes.

NATIONAL BOARD OF FIRE UNDERWRITERS' TABLE OF CARRYING CAPACITY OF WIRES.

Table A.—Rubber Insulation		Table B.—Other Insulations	
B. & S. G.	Amperes.	Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the insulating property by the heat of the wires, not from fear of igniting the insulation. The question of drop is not taken into consideration in the foregoing tables.

No smaller wire than No. 14 should be used for regular wiring.

"*Circular mils*" refers to the area of cross-section of the wire. One mil is one-thousandth of an inch, $\frac{1}{1000}$ inch, or 0.001, and the area of a square which is one mil on each side or one square mil is $0.001 \times 0.001 = 0.000001$ square inch. One square mil is 0.000001 square inch; 1624 square mils is 0.001620 square inch. The area of a circle which is 0.001620 square inch is also denominated 1620 circular mils. The area of cross-section of a No. 18 B. and S. G. wire is 1620 circular mils, or 0.001620 square inch. Each mil in the diameter of a wire indicates 0.001 inch. Each "circular mil" in the area of cross-section of a wire indicates one-millionth of a square inch.

The Insulation of Wires.—This includes all the means which are taken to limit the flow of electricity as much as possible to the wire itself, and the apparatus to which the current is led and through which it is intended to flow. Leakage of electricity may take place from one charged wire to another, or directly or indirectly to the earth. A wire may be insulated by being merely suspended in the air at a sufficient distance from other conductors. The required distance will depend upon the voltage of the current, a difference of potential of 10,000 volts between a wire and another conductor causing the current to break through the insulation of about an inch of air. *Air insulation* is good enough for all practical purposes, and is depended upon for telegraph wires, except at the points where the weight of the wire must be supported. The fact that the air is a poor conductor of electricity and may, therefore, be used as insulation, makes the installation and construction of electric apparatus much simpler than if every wire and switch and binding-post and screw had to be protected from contact with the air. Bare wires may run in grooves in various insulating materials, such as marble, slate, hard rubber, or ivory, in stationary positions, where they are not exposed to accidental contact with other wires. The connections in the ordinary double-pole knife-switch are made in this way. One wire from the battery or dynamo is secured by a binding-post which projects from the face of the slate base. The continuation of the circuit is formed by a bare wire laid in a groove on the back of the slate or marble base from the concealed end of another binding-post, which carries the hinge at one end of the gap, bridged across by one contact blade of the knife-switch. From this hinge the current follows the contact blade to the contact jaws, goes through the metal support to a wire which passes along the under side of the base to be secured to the concealed part of another binding-post. A wire passes from this binding-post to the apparatus. The return current follows a similar parallel path back through the connections on the opposite side of the double knife-switch. On the under surface of the marble switch-board of a cabinet for voltaic and faradic currents there are sometimes a dozen bare wires running in grooves and forming the connection between the various metallic binding-posts, switches, meters, and resistances on the face of the switch-board.

The old idea of the earth as a universal reservoir of electricity into which either positive or negative electricity may be allowed to escape and will be immediately neutralized is quite a good one as a working hypothesis. Take the case of an insulated conductor like a single telegraph wire; if one end of the wire is grounded, and one pole of the battery is grounded while the other is connected with the telegraph wire, a current will flow through the battery, and a meter which may be placed in the circuit and through the telegraph wire and back through the earth to the other pole of the battery. The nature of the transmission through the earth which receives thousands of different currents from natural and artificial sources must be very complicated. The hypothesis which offers the easiest explanation is that the earth at any point stands ready to supply a deficiency in either positive or negative electricity, or to remove a surplus of either kind. Demonstrable currents of electricity are produced in the immediate neighborhood of a grounded wire, and these are the ones which destroy gas- and water-pipes by electrolysis in the neighborhood of the electric railways. Leakage through the insulation along the telegraph forms an earth current which returns to the battery, and if there is no other connection, the amount of current passing through the meter will be simply the amount of leakage. From Ohm's law $C = \frac{E}{R}$, $R = \frac{E}{C}$; the resistance of the insulation along the whole line is found by dividing the electromotive force of the battery in volts by the leakage current in amperes. The standard insulation resistance of telegraph lines is 200,000 ohms per mile. For instance, the electromotive force from a battery of 20 cells will send a total current of only about $\frac{1}{10}$ milliampere through all the different slight leakage points of a mile of telegraph line.

The Resistance of Glass and Porcelain Insulators.—This is exceedingly great, and for electrotherapeutic purposes these substances may be regarded as absolute non-conductors.

The Insulation Resistance of Gutta-percha.—This material is waterproof, and when not exposed to the air, is very durable. Exposure to air and light hastens oxidation. Wires insulated with it and contained in lead tubing or submerged in water remain perfect for years. It has considerable tensile strength, resisting a traction of 1000 pounds per square inch of section before permanent elongation takes place, and having a breaking strength of 3500 pounds per square inch. A gutta-percha insulating covering on a wire adds more than enough tensile strength to a suspended wire to sustain the addition of its own weight. The electric resistance of gutta-percha varies a great deal with the temperature. It is 24 times as great at 32° F. as at 75° F. The insulation resistance at 75° F. of the gutta-percha covering of a mile of wire is equal to 920 log. $\frac{D}{d}$ megohms. Here D is the outside diameter of the gutta-percha in mils (0.001 inch), and d is the diameter of the conductor in mils. So that the insulation resistance in megohms (1,000,000 ohms) of a mile of gutta-percha-covered wire is equal to 920 times the logarithm of the number found by dividing the outside diameter in mils by the diameter of the conducting wire itself in mils. Wires from No. 18 to No. 16, if insulated by gutta-percha or rubber, which has much the same properties, require a coating at least $\frac{1}{32}$ inch thick, and should have an insulation resistance of at least 100 megohms per mile at a temperature of 70° F. Nos. 15 to 8 require an insulation $\frac{3}{64}$ inch thick; and Nos. 7 to 2 an insulation $\frac{1}{16}$ inch thick. These are for voltages between 0 and 600, and for electrotherapeutic purposes gutta-percha and rubber may be regarded as absolute non-conductors.

The Electrostatic Capacity of Gutta-percha Insulation.—A wire with an insulated wrapping forms a condenser. The metal forms the inner armature, the gutta-percha the dielectric, and the surrounding substances the outer armature. When an electromotive force is applied to the metallic wire, the primary effect is to charge this condenser, and then later comes the passage of a current through the conductor. The capacity of a condenser depends partly upon the size of the two armatures, or outer and inner conducting coatings, but also to a very great extent upon the material, size, and thickness of the dielectric. The dissected Leyden jar (p. 25), in which the charge remains upon the glass after both outer and inner coats are removed, illustrates this fact.

The electrostatic capacity is from 0.2400 to 0.3945 microfarad per mile. The larger figure is in the case of a wire in which the outside diameter of the insulation is only 2.50 times the diameter of the metallic wire; and the smaller figure is found when the outside diameter is 4.50 times the diameter of the metallic wire. The electrostatic capacity of a wire limits the rapidity with which impulses can be sent through the wire. If the full strength of the current is suddenly turned on, there is not an equally sudden impulse produced at each part of the line corresponding in time of occurrence to the distance from the generator. Besides the delay due to the distance traveled by the electric impulse, at the same rate as that of light, about 185,000 miles a second, there is a delay due to the fact that the condenser formed by the conductor and its dielectric and the surrounding media must be fully charged before the full strength of the impulse can reach any distant part of the line. The result is an impulse represented graphically by a slanting instead of a perpendicular line. The same phenomenon occurs when the current is turned off. The electric tension at any part of the wire does not suddenly subside at a period of time corresponding to its distance from the generator, but subsides only gradually as the condenser charge is lost. If the successive impulses are too rapid compared with the electrostatic capacity of the wire, the condenser charge does not have time to disappear between impulses, and an approximately constant current is the result. In telegraphy this limits the number of signals which can be transmitted to those corresponding to 135 words a minute. Wires used in electrotherapeutic apparatus, if of sufficient length to possess an appreciable electrostatic capacity, are almost always used in the form of coils, and in these the effect of other inductive influences overshadows that of the electrostatic capacity of the wire and its insulating material.

The Loss of Insulating Properties by Marble and Hard Rubber.—It will sometimes happen that a high-frequency apparatus will cease to work in consequence of the fact that the marble front or top which forms a base for the binding-posts leading from the outer coats of the Leyden jars to the resonator, and for the binding-posts leading from the inner coats of the Leyden jars to the spark-gap, has lost its insulating properties. The commonest cause of this condition is the absorption of moisture by the marble, and its becoming thus a sufficient conductor of electricity to allow the high-tension currents to pass along the marble instead of being compelled to cross the spark-gap. This may occur spontaneously in warm and moist climates. It may be due to the escape of moisture from the Leyden jars when the latter are half full of some liquid, like salt solution, forming the inner armatures. The most important cause of absorption of moisture is found in the nitrous fumes which are the accompaniment of discharges of high-tension electricity through the air. This condition will occur even if the Leyden jars and the spark-gap and resonator are entirely outside of the case containing the coil. It occurs without the presence of a liquid in the Leyden jars, and also with a wooden or a hard-rubber switchboard. The marble slab shows this condition to the eye, especially if the surface is unpolished. It looks wet and streaked, and the finger can rub off a salty or acid-tasting deposit. Prevention is better than cure in such a case, since after the marble has once become a conductor, it is very difficult to make it an effective insulator again. Four days' baking will certainly drive out every particle of moisture in the marble, but will not restore its insulating properties.

It is a good rule not to use any liquid inside the case of an *x*-ray coil or high-frequency apparatus, and especially to see that there are no imperfect contacts, with their consequent sparks and nitrous fumes.

It cannot yet be stated positively whether this disagreeable accident is due to ordinary chemic processes entirely, or whether it is due to a process of ionization of the marble itself, whereby it has permanently acquired the property of conducting electricity. In the first case, we may be able to dissolve out the disturbing chemic compounds by soaking in some solution and then drying the marble. In the second place, we shall have to adopt the present plan of discarding a piece of marble which has once become a conductor.

In the case of hard rubber the surface attracts moisture and dust, and besides undergoes a carbonizing process in the presence of high-frequency effluvia, so that this substance is not more permanent than marble for the purpose under consideration.

Glass may prove to be successful since, so far as known, the changes which it undergoes affect only the surface, causing a certain roughness which favors the deposit of metallic nitrates and dust and moisture. Its insulating qualities are probably restored by washing the deposit off the surface. This has not been definitely settled yet.

The peculiar character of the current which we have to control in this case is shown by the fact that a vivid white spark will often be seen at a binding-post. The screw may be turned down as tight as possible, and still the thin film of oxid between the two metal surfaces will offer sufficient impedence to cause the current to leap across an air-space of an appreciable fraction of an inch.

A **lightning arrester** is always required when wires enter a building above ground. It is an arrangement for leading a charge of high-tension atmospheric electricity to the ground, instead of allowing the current to pass into the house along the wires, with danger to the instruments, house, and occupants. The general principle is to have an insulated wire, as heavy as No. 16, thoroughly well grounded, and terminating in a metal plate with saw teeth supported upon the same insulated base, with a similar metal plate which forms part of the electric supply circuit. The sharp points of the two plates are bare, and only a fraction of an inch apart, but normally none of the current will leave the electric circuit and leap across the non-conducting air-gap between the two sets of points. The high-tension charge of atmospheric electricity, however, with its enormously high frequency (millions of oscillations a second), flashes across this space and is safely led to earth. It is true that the ohmic resistance of the air-gap is infinitely greater than that of the wires in the various instruments, but the high tension makes it possible for the atmospheric electricity to overcome this resistance. Currents of extremely high voltage and extremely rapid oscillations are subject to an inductive impedence which will cause them to leap a considerable air-space and follow the shortest path rather than follow a long conducting path, even though the latter has ample carrying capacity. Another form of lightning arrester is made by wrapping half a dozen turns of insulated wire around the electric-light wire before it enters the house. The other end of this insulated wire is grounded, as in the first type of lightning arrester, by being soldered to a metal water-pipe or to a mass of iron buried in a pit filled with damp charcoal.

Electrolytic Lightning Arresters.—These afford a short circuit for the current whenever it becomes of a sufficiently high voltage to overcome the resistance of the liquid. The resistance can be so delicately adjusted that even a small percentage of increase over the ordinary operating voltage will be prevented from passing into the house circuit (Fig. 159). The principle is the same as in the familiar electrolytic interrupters used with x-ray coils.

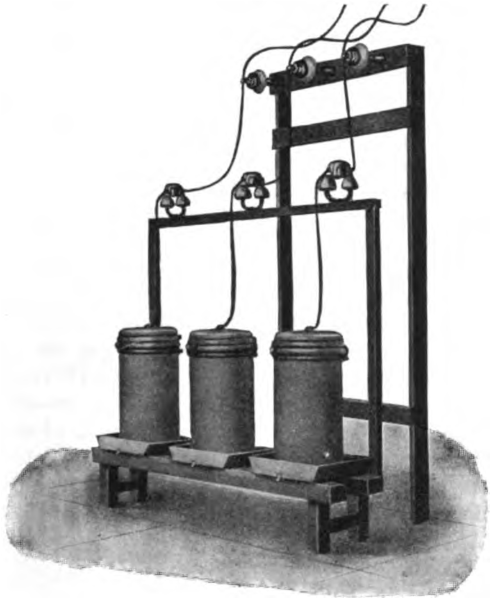


Fig. 159.—Westinghouse electrolytic lightning arrester.

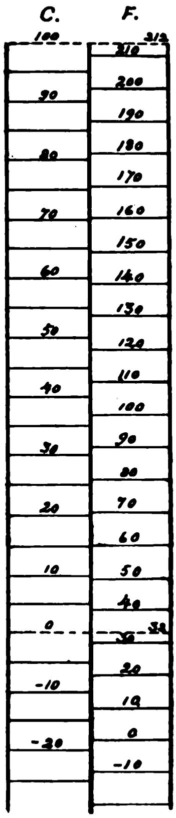


Fig. 160.—Centigrade and Fahrenheit thermometric scales.

VALUES OF ENGLISH AND METRIC MEASURES.

One meter = 3.2809 feet = 39.37 inches.
One centimeter = 0.3937 inch, or about $\frac{1}{10}$ inch.
One millimeter (0.001 meter) = 0.03937 inch, or about $\frac{1}{25}$ inch.
One kilometer (1000 meters) = about $\frac{5}{8}$ mile.
One gram = 15.432 grains (Troy).
One kilogram (1000 grams) = 2.20 pounds Avoirdupois.
One cubic centimeter (1 c.c.) = 0.06103 cubic inch.
One liter (1000 c.c.) = 61.03 cubic inches = 0.8804 quart.
One degree Centigrade = $\frac{9}{5}$ degree Fahrenheit.
0° Centigrade = 32° Fahrenheit = freezing-point of water.
100° Centigrade = 212° Fahrenheit = boiling-point of water.
100° Fahrenheit = − 37.8° C.
39° Fahrenheit = 3.8° C. = maximum density of water.
60° Fahrenheit = 15.5° Cent. = temperature at which electric resistances are usually measured.

MEASUREMENTS OF RESISTANCE

Different substances have specific conductivities, and a conducting path consisting of a given length and area of cross-section will present a resistance which may be calculated by reference to a printed table. Any change in chemic composition or in temperature or other conditions produces a change in electric resistance. This fact is illustrated in the most wonderful manner by the conductivity of water and aqueous solutions, especially of acids and salts. Taking the conductivity of silver as 1, that of the purest distilled water is about $\frac{7}{1,000,000,000}$, while a solution of sulphuric acid one to six of water, has a conductivity about $\frac{100,000}{100,000,000}$ that of silver. This is the solution which is used as the electrolyte in the liquid interrupter for *x*-ray coils. The smallest admixture of any other substance multiplies the conductivity of water to a perfectly enormous extent. The electric resistance of a disk of pure water 1 millimeter thick is as great as that of a rod of silver of the same cross-section, but twice as long as the distance from the earth to the moon. One electric resistance which has to be tested in electrotherapy is that of the insulation in different parts of the apparatus and in the covering of the wires. Another is the internal resistance of the battery. These two tests are sufficiently described on pp. 88 and 227. Another is the resistance of the wires themselves, while others are those of the living tissues, especially the skin, which is highly resistant, and the resistance of physiologic fluids, such as the urine and blood.

Ohm's law, that the current in amperes is equal to the electromotive force in volts divided by the resistance in ohms, furnishes the basis for every calculation in regard to resistance. The resistance is equal to the electromotive force divided by the strength of the current $R = \frac{E}{C}$.

Testing Resistance by Simple Substitution.—An unknown resistance, R, is connected in series with a constant battery and a galvanometer, G, and the current strength is noted. Then a standard resistance, R′, is substituted for the unknown resistance, and is varied until the galvanometer shows that the current strength is the same as in the first instance. Then $R = R'$.

It may not always be practicable to vary the standard resistance so as to make the current equal to the one to be tested, and in that case a calculation is to be made, based upon the relative strength of the current with the two different resistances. If *d* is the deflection obtained with the unknown resistance, and *d′*, that obtained with the standard resistance, and G is the resistance of the galvanometer (it is necessary to know this), and the internal resistance of the battery is so small in comparison with R, R′ and G as not to be considered; then $R = \frac{d'}{d}(R' + G) - G$.

The standard resistances used in the foregoing tests are obtained by the use of a resistance box.

It is necessary to take precautions to secure joints as free from resistance as possible or the results will be vitiated. The ends of the wires should be scraped free from oxid or grease, and where delicate measurements are attempted, the different contacts should be made by dipping the ends of the two wires into the *same cup of mercury.*

Measuring Resistance by Difference in Potential.—This is a method which is delicate enough for testing the resistance, even of short lengths of wire. It depends upon the fact that there is a difference in potential between any two points of an electric circuit. And if two separate sets of points are tested along the same circuit, the two differences in potential will be directly proportional to the resistance in the portions of the circuit between one pair of points and the resistance between the other pair. Fig. 161 shows the arrangement of an apparatus for making this test. G is a sensitive galvanometer, a mirror galvanometer, for example, with a high resistance as compared with the resistance which is to be tested. E is a constant current battery, such as several Daniell cells, and K is a key by means of which the circuit is closed or opened. R^2 is the resistance to be measured, and the connection at either end may be made as in the diagram, by means of a mercury cup, or the wire may be soldered to the other wires. R' is a standard variable resistance, such as a 100 cm. of German-silver wire of a certain size, with a known resistance per centimeter. There is a very perfect electric connection between the two resistances. A double pole switch, not shown in the diagram, makes either the connection shown by the heavy lines in the diagram, or that shown by the dotted lines. In the former case the galvanometer is in shunt to the standard resistance R', and in the latter case to the unknown resistance R^2. R^1 is to be varied until, as we turn the switch, making alternately one connection and then the other, the same amount of deflection is produced. Then $R^2 = R'$. In other words, the resistance utilized at R' indicates exactly the resistance of the object which was to be tested. The adjustment may be made by varying the length of the wire which is to be tested if it is a wire, and in such shape that a sliding contact may be had with it. The original 100 cm. of the standard resistance wire is unvaried, and we find how many inches of the unknown wire have a resistance equal to that of 100 inches of the standard wire. From this it is easy to calculate the resistance in ohms of any desired length of the wire under test.

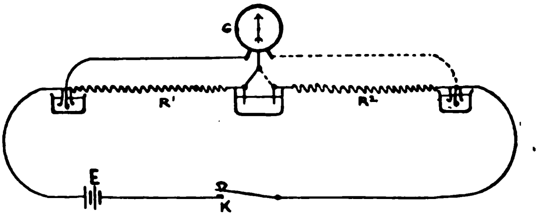


Fig. 161.—Measuring resistance by testing difference in potential.

This method, by means of comparative difference in potential, is adapted to measuring the resistance of a short wire, or such a resistance as occurs at the contact between the brushes and the commutator section in a motor or a dynamo.

Generally speaking, the resistance of different physiologic tissues and fluids is so great as not to be conveniently measured by this method.

Measurement of Resistance by Wheatstone's Bridge.—This is on a very similar principle to that of the measurement of the electromotive force by Lumsden's method of opposed electromotive forces.

The diagram (Fig. 162) shows the general arrangement. One of the wires from a constant current battery, E, divides into two paths, A and B, having fixed resistances. The other wire from the battery divides into two paths, one of which is a variable standard resistance, R^1; and the other is the unknown resistance, R^2, which is to be measured. A wire from A is joined to a wire from R^1 at the point 1 in the diagram, and a wire from B to one from R^2 at 2. Between the points 1 and 2 is a cross wire with a galvanometer, G. The current being turned on, there will be an electromotive force at 1, tending to send a current through the galvanometer toward 2; and at 2 there will be an electromotive force tending to send a current toward 1. The fixed resistances and the variable standard resistance are regulated with reference to the resistance to be measured, so that the galvanometer shows no deflection. When this is the case, it is capable of demonstration that the following relation exists between the different resistances: $A : B :: R^1 : R^2$. Consequently $A\ R^2 = B\ R^1$, and the products of opposite sides of the bridge are equal to each other. Therefore, $R^2 = R^1 \frac{B}{A}$.

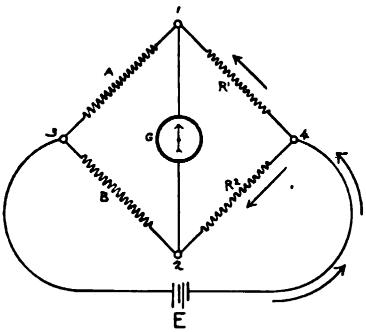


Fig. 162.—Wheatstone's bridge used for measuring resistance.

B and A are sometimes equal, and in that case $R^2 = R^1$. More often, however, B is 10, 100, or 1000 times A, and then we must first find R^1 by adjusting its resistance until the galvanometer shows no deflection, and then multiplying the value of R^1 by 10, 100, or 1000, as the case may be.

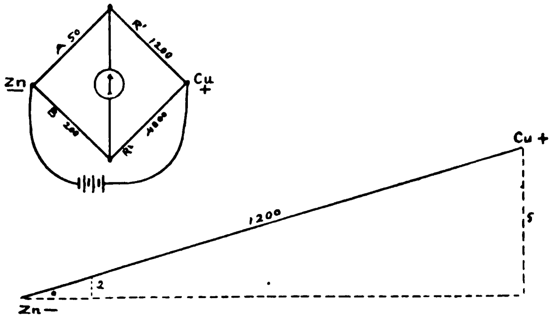


Fig. 163.—Drop in potential along a uniform resistance proportional to distance between two poles of a battery. The Wheatstone bridge equivalent.

On the other hand, the unknown resistance may be so small that it will be desirable to make A 10, 100, or 1000 times the value of B. In that case, having found the value of R^1, this value is to be divided by 10, 100, or 1000, for R^2 bears the same relation to R^1 that B bears to A.

Still another condition may occur. It may not be practicable to secure an exact balance, shown by the absence of deflection in the galvanometer. The amounts of deflection with the nearest available values of R^2 above and below the true value form the basis for the calculation of the small fraction to be added to or subtracted from the nearest available trial resistance.

The electric bridge or balance is made up in different forms, and in some there is a slight modification of the theoretic combination of parts, but they all depend upon the same principle: that equal opposed electromotive forces produce no deflection in a galvanometer. The equality of the electromotive forces at the points from which the galvanometer circuit is derived may be illustrated by the diagrams (Figs. 162 and 163).

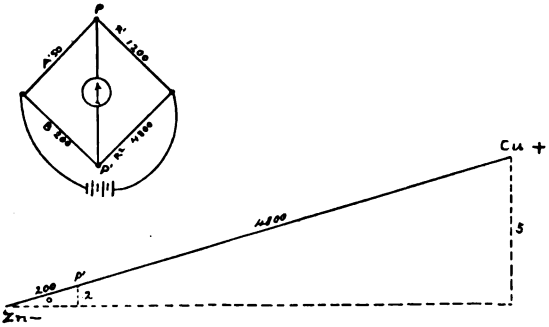


Fig. 164.—Another example of the conditions in Fig. 162.

Fig. 163 shows a difference of five volts in potential between the point marked Cu + at the positive end of the bridge, and the point marked Zn – at the negative end of the bridge. Representing electromotive force as height, we should have Zn – at the zero level, and Cu + at a height of five units (representing ohms). The line joining these two points represents resistance, and the point P has 50 ohms between it and Zn –, and 1200 ohms between it and Cu +. In other words, P is a point along the circuit separated from Zn – by only one-twenty-fifth as much resistance as there is between Cu + and Zn –. According to very well-established principles, the difference in potential between P and Zn – is only one-twenty-fifth as much as that between Cu + and Zn –. The electromotive force at P is, therefore, correctly represented by a height of 0.2 unit (equivalent to 0.2 volt).

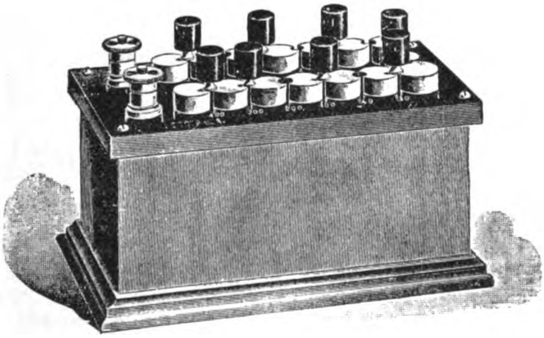


Fig. 165.—Student's resistance box.

Turning now to Fig. 164, we find the same potential at Cu+ (five volts) and that the resistance between P¹ and Zn – (200 ohms) is one-twenty-fifth that of Cu+ or 0.2 ohm.

There is the same potential at P and P¹ when the four resistances bear the proper relations to each other, and having the same potential no flow of current occurs between P and P¹.

The Resistance Box.—The fixed and variable resistances employed in testing electromotive force or resistance are usually obtained from a box containing several coils of wire having different standard resistances varying from 0.1 ohm to perhaps 10,000 ohms. In some cases the different resistances are introduced into the circuit by pushing a plug into a hole, and in other cases it is by pulling a plug out of a hole, and in still other cases there are sliding contacts by which the resistance is changed. These resistance coils, of course, have a tendency to heat up, but this is not dangerous, because the current is usually a small one obtained from a few Daniell cells and measured in milliamperes rather than in amperes, and it is turned on only for a short time. A resistance coil of 1000 ohms might consist of 651 feet of No. 31 German-silver wire ($\frac{1}{100}$ inch in diameter), and would weigh about 1½ ounces. Smaller resistances may be made of larger and shorter wire.

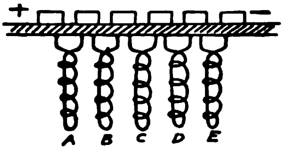


Fig. 166.—Resistance coils (schematic).

APPROXIMATE RESISTANCE OF GERMAN-SILVER WIRE

B. W. G. No.	Diameter.		Resistance.	
	Inches.	Millimeters.	Ohms per Foot.	Ohms per Meter.
6¼	0.200	5.030	0.0030	0.0125
8¼	0.160	4.060	0.0065	0.0193
10	0.136	3.450	0.0080	0.0270
12	0.107	2.720	0.0130	0.0430
14¼	0.080	2.030	0.0230	0.0770
18	0.050	1.270	0.0600	0.1980
20	0.036	0.914	0.0890	0.3830
24	0.022	0.558	0.3100	1.0240
26	0.018	0.457	0.463	1.5290
31	0.010	0.254	1.530	5.1500
36	0.007	0.106	9.390	31.0000

The resistance of German-silver wire is about 13.5 times that of copper wire of the same size.

Testing the Resistance of a Galvanometer.—If another galvanometer is available, the Wheatstone bridge is used. The galvanometer whose resistance is to be tested is placed in the position of R² in the diagram (Fig. 162), and the other galvanometer in the cross circuit of the bridge. The resistance of the unknown galvanometer with or without a shunt is then tested as if it were any other resistance.

Thomson's (Lord Rayleigh's) method is useful when there is no other galvanometer available. A Wheatstone bridge is used (Fig. 167), and the galvanometer to be tested is placed in the ordinary position of the unknown resistance. At the place upon the cross circuit where a galvanometer is ordinarily placed there is none, but instead there is a key for opening and closing this cross circuit. A and B are fixed resistances, and R¹ is varied until the deflection shown by the galvanometer is the same whether the cross circuit is closed or open.

Then $A R^1 = B G$ and $G = R^1 \frac{A}{B}$. This method has the advantage that it is independent of the internal resistance of the battery. One wire from the battery should go to the junction between the two lowest resistances, and the other wire to the junction between the two highest resistances.

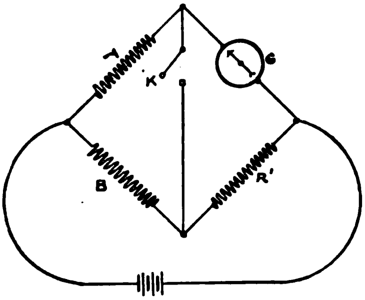
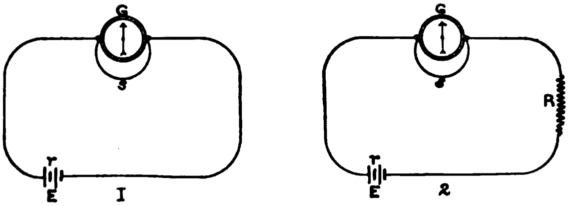


Fig. 167.—Measuring resistance of a galvanometer when no other galvanometer is available.

To Measure the Internal Resistance of a Battery.—The simplest and readiest method is illustrated in Figs. 168 and 169. The battery has two short heavy copper wires, and the galvanometer is shunted by a short thick copper wire, so that the resistance of the conducting cords and $\frac{G s}{G + s}$, the joint resistance of the galvanometer and its shunt, may be neglected. These resistances are to be very small in comparison with the internal resistance of the battery. The current is turned on, and the deflection of the galvanometer is noted. Then a resistance is introduced at R, and is varied until the galvanometer indicates only half as strong a current as before. Since the current is only half as strong, the resistance must have been doubled. Therefore r (the battery resistance) $+ R = 2r$. And $r = R$.



Figs. 168 and 169.—Measuring internal resistance of a battery.

Testing Electrostatic Capacity.—The static charge on an insulated conductor may be measured by discharging it through a ballistic galvanometer. The latter is any galvanometer in which the movable part is heavy enough to cause a series of pendulum oscillations in consequence of a momentary discharge. Such an instrument must be graduated by experiment with standard quantities of electricity, and this is done by discharging known capacities charged to known potentials through it.

Measurement of Electric Capacity.—This may be done by charging the body to a known potential, and then measuring the amount of electricity by discharging it through a ballistic galvanometer.[1]

A certain amount of electricity may charge a body of large capacity to a low potential, and have very different properties (notably in that it produces no noise or shock when discharged) from that of the same

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[1] A body of a known capacity stores up four times as much electricity if charged to twice the potential. The charge varies directly as the capacity and as the square of the potential.

amount of electricity charging a body of small capacity to a high potential.

The difference may be likened to that between the same amount of heat which, when absorbed by a pint of water, will not warm it perceptibly, but if applied to a needle, will make it red hot and capable of searing the flesh.

Condensers.—Leyden jars and the many-leaved condensers of induction coils have a definite capacity which depends partly upon the nature, size, and thickness of the armatures and of the dielectric separating them. Every object, solid, liquid, or gas, which can receive an electric charge has a certain capacity, and exhibits the properties of a condenser to a greater or less extent according to circumstances. A submarine cable, for instance, has a large electrostatic capacity which shows itself in two ways: first, it takes an appreciable amount of electricity and a certain length of time to charge it to such an extent that it begins to act as a conductor and deliver current at the other end. Second, when the current is turned off, the cable has a certain charge which causes it to continue to yield a current for a certain time. The currents through the cable do not, therefore, begin and end with the sharp click of the transmitter, and the rapidity with which signals can be sent through it is limited. Coils of insulated wire are used as capacities in connection with certain electric transformers. Leyden jars are usually charged with very high-tension electricity, generated by a static machine, and receive, therefore, a magnitude of charge which is quite wonderful when the small capacity of the jar is considered. The Leyden jar or some equivalent thereof with a perfect and practically indestructible dielectric is the type of condenser that must be used for charges of very high potential. The capacity may be increased by using a larger Leyden jar or connecting a number of Leyden jars and charging them all at the same time. There are two principles upon which Leyden jars may be connected. They may be connected in parallel, all the inner armatures being connected to form one pole, and all the outer armatures connected to form the other pole. The capacity of the condenser thus produced is equal to the sum of the capacities of the individual Leyden jars. The other way is to connect the inner armatures of one jar with the outer armature of the next, and the inner armature of that with the outer armature of the next, and so on. This is called a series connection, and the two poles of such a condenser are formed by the outer armature of the jar at one end of the series, and the inner armature of the jar at the other end of the series. This is an arrangement similar to that in which Leyden jars are charged by cascade. The capacity of a condenser made up in this way is equal to the reciprocal of the sum of the reciprocals of the capacities of the individual Leyden jars—

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}.$$

A Leyden jar with a total coated surface of 1 square meter and with glass 1 millimeter thick has a capacity of $\frac{1}{56}$ microfarad. The capacity of the Leyden jars used in high-frequency apparatus is about 0.0018 microfarad, of three such Leyden jars connected in series the capacity would be—

$$C = \frac{1}{\frac{1}{0.0018} + \frac{1}{0.0018} + \frac{1}{0.0018}} = \frac{1}{\frac{3}{0.0018}} = \frac{0.0018}{3} = 0.0006 \text{ microfarad.}$$

Testing the Capacity of a Condenser by Direct Discharge.—This is a simple method which yields approximate results. It requires the use of a mirror galvanometer or a sensitive astatic galvanometer, and of a standard condenser of known capacity, C_1. A standard condenser (Fig. 170) is a necessary part of any outfit for making tests of electric capacity. Such a standard capacity of ⅓ microfarad may contain 1200 square inches of tin-foil in small sheets separated by paraffin paper. The same battery is used to charge first the standard condenser, and then the condenser whose capacity is to be measured. The standard condenser is discharged through the galvanometer, and the amount of deflection, d_1, is noted. Then the condenser with an unknown capacity, C_2, is discharged through the galvanometer, and its deflection, d_2, is noted. Then—

Fig. 170.—Standard condenser.

$$C_1 : C_2 :: d_1 : d_2$$

$$\text{Or } C_2 = C_1 \frac{d^2}{d_1}.$$

Thomson's (*Rayleigh's*) *Method of Testing the Capacity of Condensers and Conductors.*—The capacity to be tested for electrotherapeutic purposes may be that of the secondary winding of an *x*-ray coil or transformer.

The Apparatus Required (Fig. 171).—B is a battery of about ten Daniell or other constant voltaic cells. This must be well insulated from the ground, as well as between its two opposite charges.

*Key*¹ is a key by means of which the circuit is made or broken close to one pole of the battery.

*Key*² is a key by which the circuit is made or broken between the battery, and one end of the coil of wire whose capacity is to be tested. The latter is marked *coil*.

Coil in the diagram has the other end of its wire free.

C^2 is the capacity of the coil expressed in microfarads.

Key^3 makes or breaks the circuit at the point where a wire leads from the battery to one electrode of the standard condenser, whose capacity is C^1 expressed in microfarads, and whose other electrode is grounded.

From a point between the battery and the standard condenser a side line crosses to the earth through R^1, which is a variable resistance.

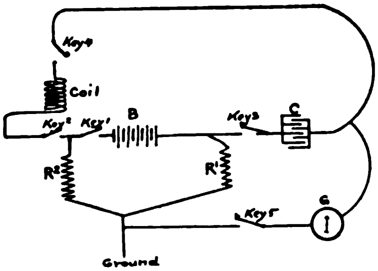

Fig. 171.—Testing the capacity of a coil.

From a similar point on the circuit from the battery to the coil a side line passes to earth through R^2, which is a fixed resistance.

G, the galvanometer, is on a line connected at one end with the junction of these two resistances, at the point where they are fastened to a ground wire, and at the other end with the circuit between the standard condenser and the coil.

Key^5 makes and breaks the galvanometer circuit.

The test is made as follows: 1. Close *key*^{1}, then V^1 and V^2 may be the potentials at the points of junction of the battery wires with the resistances R^1 and R^2 leading to earth. The current is the same through the battery and through both resistances, since these are in series. The voltage, therefore, must be proportional to the resistance, and we have—

$$V^1 : V^2 :: R^1 : R^2.$$

2. While *key*^{1} is still closed, close *key*^{2} and *key*^{3} simultaneously for a fixed time, charging both the capacities. The standard condenser C^1 is charged to a potential of V^1, while the capacity C^2 to be measured is charged to a potential of V^2.

Key^5 and *key*^{4} which lead from the free extremity of the coil to the condenser, have been open during this time, and the proximal electrode of the standard condenser has been connected only with the negative pole of the battery. The capacity to be measured has been connected only with the positive pole of the battery. The proximal armature of the standard condenser and the capacity to be measured are, therefore, charged with negative and positive electricity respectively.

The quantity of negative electricity received by C^1 is $Q^1 = V^1C^1$, while the amount of positive electricity received by C^2 is $Q^2 = V^2C^2$.

3. Open *key*^{1} and *key*^{3}, cutting off all connection with the battery. Close *key*^{4}, allowing the positive and negative charges of C^2 and C^1 to mix. Their potentials are, of course, immediately equalized, and if the quantities are equal, both charges are neutralized. Open *key*^{5} to test this. The occurrence of a deflection indicates an excess either of positive or negative electricity in the combined capacities, and another trial must be made with another value, to the variable resistance R^1. This is repeated until a complete equality and neutralization of the charges in the two capacities are indicated by the absence of deflection in the galvanometer. We now have the factors for the calculation of the unknown resistance. These factors are the resistances of the two

earth shunts determining the voltages required to charge the standard condenser and the unknown capacity with the same quantity of electricity. An electric capacity is like a compressed air-tank—just so much electricity can be forced into it and will completely fill or charge it at a certain pressure; but four times as much can be forced in and will be required fully to charge it at twice that pressure. No less amount than this will produce the specified pressure in the condenser.

The following is the calculation:

$V^1 C^1 = V^2 C^2$. (The quantities of electricity in the two capacities are equal.) And from this the following proportion is obtained:

$$V^2 : V^1 :: C^1 : C^2.$$

It is already known that—

$$V^2 : V^1 :: R^2 : R^1.$$

Therefore,

$$R^2 : R^1 :: C^1 : C^2, \text{ and from this}$$

$$C^2 = \frac{R^1}{R^2} \times C^1 \text{ microfarad.}$$

There are other methods of measuring the capacity of condensers or conductors, but this one is accurate and readily available for laboratory work.

A set of Leyden jars of equal capacity connected in parallel has a combined capacity found by multiplying the capacity of one Leyden jar by the number of jars. The same jars connected in series have a combined capacity, which is found by dividing the capacity of one jar by the number of jars.

Other different combinations may be made corresponding to the multiple-series and series-multiple arrangement of voltaic cells in a battery. These give any desired capacity, large or small, if there are a sufficient number of Leyden jars available.

Rochefort's monolith condenser is exactly analogous to a Leyden jar containing the same number of square inches of metal foil, and separated by the same thickness of glass. But a flat glass plate considerably larger than the armatures is used instead of a jar, and the distal surfaces of the armatures are covered by glass plates which extend beyond the metallic surface, and are soldered to the dielectric glass plate by a cement having practically the same composition as the glass. The condenser is practically a solid sheet of glass, containing in its interior two metal plates separated from each other by a certain thickness of glass. At opposite points on the periphery of the glass there are metallic connections from the two armatures. This method of construction prevents the leakage of electricity which takes place all around the edges of the armatures in a Leyden jar, and which is visible as a violet-colored light and as a regular crown of violet-colored sparks at the moment of discharge. The armatures in the monolith condenser present no visible evidence of activity. As made by Rochefort, there are only a few small luminous points between the glass plates where the contact is not absolutely perfect. These places are miniature Geissler vacua, and do not cause any demonstrable loss of electricity, and do not tend to enlarge.[1] The armatures are of copper foil, and are about 6 inches

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[1] Annales d'Electrobiologie et de Radiologie, Lille, France, February, 1906.

in diameter; while the complete condenser with an ebonite top and bottom and metal binding-posts forms a disk about 12 inches in diameter and about 1½ inches thick. Two or more of these condensers can be made into a thicker disk, and may be connected in parallel or in series or in a combination of the two ways. This connection is a remarkably simple matter, assuming that the condensers are all placed one on top of the other; the binding-posts of the top armatures in the various couples may be turned toward one side and those of the lower armatures turned toward the opposite side (Fig. 172). A simple metallic connection binds together all the connections on one side, and forms one pole of a condenser having a capacity equal to the sum of the capacities of all the separate couples, while all the lower plates are bound together in the same way to form the opposite pole. These condensers can be equally well connected up in series. Turn the binding-posts so that in the connection from the upper plate in the first condenser shall be toward the right, and from its lower plate to the left; and that from the upper plate of the second condenser to the left, and from its lower plate to the right. The connection is made from the lower plate of the first to the upper plate of the second couple at the left of the combined condenser; and from the lower plate of the second couple to the upper plate of the third couple (Fig. 173).

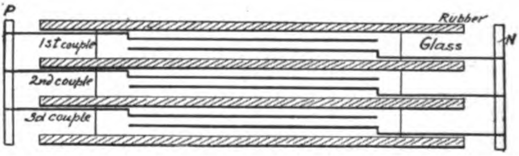

Fig. 172.—Rochefort's monolith condenser. Usual parallel connection.

Leyden jars or Rochefort's monolith condensers are used for the extremely high-tension charges of the static machine and high-frequency apparatus, because glass forms a highly resisting dielectric, and is not so liable to puncture as paper, wax, or mica, and is freer from imperfections. The glass wall of a Leyden jar or the layer of glass between the armatures in the monolith condenser will resist the electric tension required to produce a 6-inch spark through the air, but if a puncture does occur, the discharge melts a path for itself through the glass, and this usually destroys the condenser. Other dielectrics sometimes used for high-tension condensers are oil and compressed air or other gases. There are two chief requirements in the case of a non-conducting layer used as the dielectric of a condenser for high-tension electricity —one, inductive capacity, and the other, impenetrability.

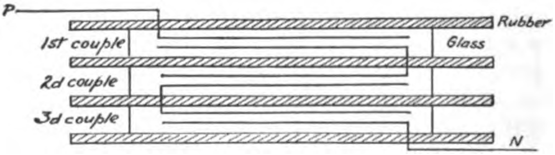

Fig. 173.—Rochefort's monolith condenser. Series connection.

The *condensers used for the primary current of induction coils* and for other currents of low tension and great volume consist of a very large surface made up as lightly and compactly as possible. Each armature has many sheets of tin-foil with a total surface of about 75 square yards for a large coil. The sheets of tin-foil are usually separated from each other by thick paraffined paper or by sheets of mica. There is not the same danger of perforation as in the case of high-tension currents. The condenser armatures and dielectric are consolidated under heat and pressure, so as to form a solid block which may be concealed in the base of the coil or may be separate from it. Such a condenser usually has its armatures connected in surface or parallel, so that the first and the third and the fifth, etc., metal sheets project at one end, and are all fastened together with one electrode, and really form a single armature with an enormously large surface. The other set of metal sheets, the second, fourth, sixth, etc., project beyond the other edge of the paraffin papers, and are united by a single electrode to form another single armature of very large surface.

Fig. 174, A, shows in a diagrammatic way the construction of such a condenser, with the two opposite sets of metal sheets interlacing and paraffined paper preventing contact between any metal sheet with any of the opposite set. In actual construction the metal sheets are much closer together; there is no air-space—only the thickness of the paper between them. The external extremities of each set of metal sheets are not joined by a cross rod, as in the diagram, but are pinched together by a metal clamp. There are many more of the different layers than are shown in the diagram.

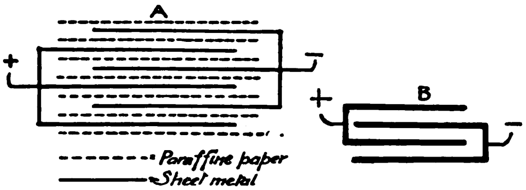

Fig. 174.—Condenser for induction coil.

Fig. 174, B, has been devised by the author as a convenient diagrammatic representation of a condenser. One set of metal sheets connected with the negative pole of the electric generator interlace with the set connected with the positive pole. The dielectric separating the two sets of metal sheets is represented by the space between them in the diagram.

Charging and Discharging a Condenser.—The familiar process of charging a Leyden jar is shown in Fig. 175, where one electrode (from the internal armature in the diagram) is touched to the positive pole of a static machine and the other electrode (from the external armature in this particular case) is connected with the negative pole of the static machine or with the ground. In the condition shown in the diagram the Leyden jar is charged, its inner armature with positive and its outer armature with negative electricity.

Analogous to this is the condition of the many-leaved condenser shown diagrammatically in Fig. 176. A direct connection exists between the negative pole of a voltaic battery and one electrode of the condenser, whose leaves are, therefore, charged with negative electricity. The other set of metal leaves are charged with positive electricity by direct connection with the positive pole of the battery. No current can flow under the conditions shown in this diagram, since the two armatures are separated by a non-conducting dielectric and the circuit is not completed in any other way. If the battery should suddenly give out, the condenser would discharge itself through the conducting wires and through the electrodes, and the liquid electrolyte of the battery. The direction of the current from the condenser would be from its positive electrode through the conductor, through the battery, and through the other conducting cord to the negative electrode of the condenser. The path thus described corresponds exactly with the discharging rod by which a Leyden jar may be discharged. Fig. 177 shows how such a metal rod, held by an insulated handle, may be applied to the two electrodes of a Leyden jar, and allow the current to flow between the two until the positive and negative charges are neutralized.

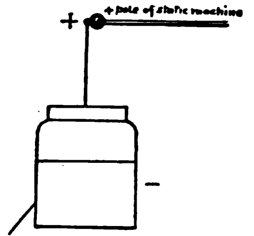

Fig. 175.—Charging a Leyden jar from a static machine.

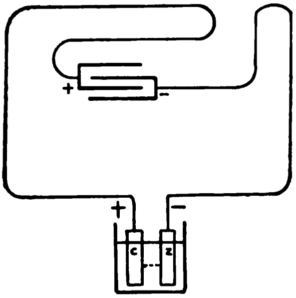

Fig. 176.—Charging a condenser from a voltaic battery.

Here as well as elsewhere the direction taken by the positive charge is called the direction of the current.

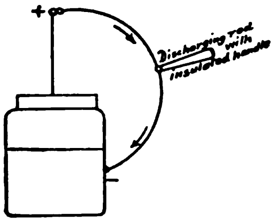

Fig. 177.—Discharging a Leyden jar by means of a discharging rod with an insulated handle.

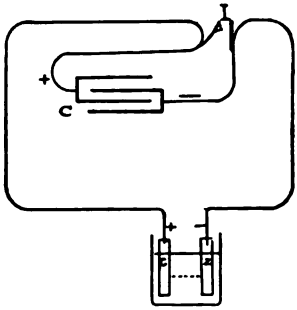

Fig. 178.—Condenser in shunt to a voltaic battery circuit and becoming charged when the latter is open.

Fig. 178 shows a similar case to that in Fig. 176, except that there is an interrupter at I, which is open in this diagram, but which, when closed, forms a complete circuit for the battery. The interrupter being open, there is no current flowing, but the positive and negative plates of the condenser are charged with electricity.

Closing the interrupter as in Fig. 179, a double effect is produced. First, the condenser becomes discharged by the passage of a current from its positive armature through a short conducting cord to the interrupter, and thence back through the other short conducting cord to the other electrode of the condenser. Second, a current flows from the positive pole of the voltaic battery through the conducting cord to the interrupter, and thence through the other conducting cord to the negative pole of the battery, and through the liquid electrolyte to the positive pole. As long as the interrupter is closed the battery current continues to flow, and the condenser remains uncharged.

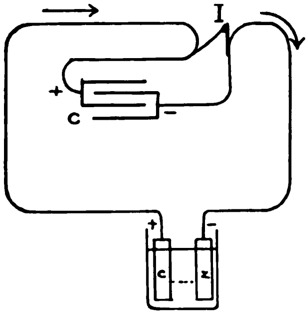

Fig. 179.—Condenser discharging when voltaic circuit is completed.

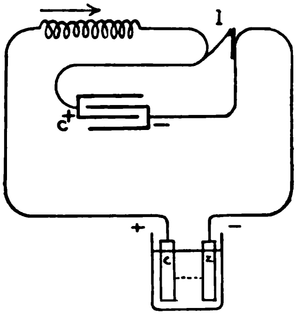

Fig. 180.—Condenser in shunt to the primary wire of an induction coil. Complete circuit and discharge of condenser.

If, now, the interrupter opens as in Fig. 178, the battery current continues for a short time, not making a complete circuit, but flowing into the condenser until it is fully charged. Then things remain as described in the first reference to Fig. 178, until the interrupter is again closed.

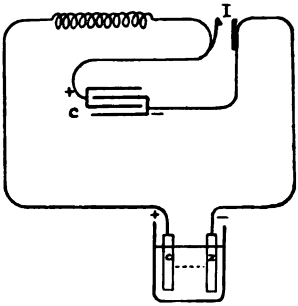

Fig. 181.—Condenser becomes charged when the primary current of an induction coil is interrupted.

The Effect of a Condenser Upon the Primary Current of an Induction Coil.—The diagrams in the preceding paragraphs have been devised by the author as a preliminary to those illustrating conditions in actual practice.

Fig. 180 shows the condition when the interrupter is closed. The condenser is not charged. A current flows from the positive electrode of the battery through the conducting cord, through the primary coil and interrupter and conducting cord to the negative electrode of the battery, and through the liquid electrolyte to the positive electrode. At the beginning this current induces a momentary current in the opposite direction in the secondary coil, which surrounds the primary coil, but is not shown in the diagram.

The interrupter is then opened as in Fig. 181, and this is automatic and is produced in many cases by the magnetic attraction of the soft-iron core of the primary coil acting upon the hammer of the interrupter. The chief object is to cause the current through the primary coil to cease, and by that very act generate a current in its own direction in the secondary coil. But with the cessation of the battery current in the primary coil there occurs an induced or extra current, produced in the primary coil by self-induction. This extra current has two deleterious effects. First, it is of high tension, and sparks to a disagreeable and injurious effect across the open interrupter; and, second, it forms a sort of continuation of the primary current, which should cease quite promptly in order to induce, at its break, the best possible current in the secondary coil.

The beneficial action of the condenser is in the correction of these two deleterious effects of the extra current in the primary coil. This extra current rushes first into the condenser and charges its many-leaved armatures, one with positive and the other with negative electricity, and the capacity of the condenser is calculated to be sufficient to receive all the current which would otherwise form a spark across the open interrupter. By the time the condenser is fully charged with this high-tension electricity the high electromotive force of the extra current in the primary coil has disappeared. The condenser is now fully charged at a higher tension than the electromotive force of the battery, and it at once becomes discharged. It sends a current from its positive electrode through the conducting cord, the battery, and the other conducting cord to the negative electrode of the condenser. The interrupter is open during this time, which is very short. The discharge from the condenser also surges into the primary wire when it is in the opposite direction to the battery current, and its effect on the current in the primary coil is not only to bring the primary current to a stop almost as soon as the interrupter has opened, but, in addition, to produce a countercurrent in the primary coil. The latter has an inductive effect on the secondary coil, augmenting the effect of the cessation of the primary current. The break current or the secondary current induced by the cessation of the primary current and flowing in the same direction as the primary current is of greater strength, and has more important uses than the make current. The condenser, therefore, has great value in every case in which the extra current is a disturbing factor in depriving the coil of the effect of a prompt and complete cessation of the primary current at the time that the interrupter is opened.

Cases in which an Induction Coil Requires a Condenser.—Coils using a heavy primary current, 6 or more amperes, and a mechanic interrupter, always require a condenser. *x*-Ray coils, therefore, except those with a liquid interrupter, require a condenser.

Cases in which an Induction Coil Does Not Require a Condenser.—Coils which are intended to carry only a small primary current do not usually need a condenser, although they are usually made with mechanic interrupters. Faradic coils are in this class. The Wehnelt and Caldwell-Simon interrupters produce a quality of break in the primary current which yields an excellent inductive effect without a condenser.

The familiar experiment of interrupting the flow of the primary current by cutting the wire with a bullet from a rifle produces so rapid and complete a break of the primary current that the condenser proves to be unnecessary.

The Potential and Capacity of a Leyden Jar.—An insulated metal ball (Fig. 182, A), connected with the positive pole of a static machine, will be charged to the same potential or the same number of volts, V, as that pole of the machine, and it has been established by experiment that the quantity of electricity which it will receive or its capacity at that potential is $q = VR$, R being the radius of the sphere A.

If this sphere be surrounded by an external conducting shell, B, separated from the sphere A by a layer of air or other dielectric substance and connected with the earth, the static machine still continuing to maintain a potential of V, the inner positive sphere will at first induce a charge in the outer shell which will attract negative electricity into the shell from the earth, and repel positive electricity from it into the earth. The negative charge upon the shell will in turn act upon the inner sphere A, and attract into it a larger positive charge than it could have received without this influence. This is the well-known principle of the condenser. Two conductors separated by a non-conducting dielectric have an increased capacity for electricity, and if charged to the original potential V, each will contain a quantity of electricity +Q and −Q, which is greater than either could have been made to receive from the same source of potential when by itself.

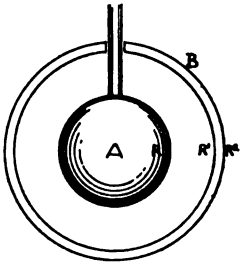

Fig. 182. — Insulated metal ball inside a hollow metal sphere.

The potential V of the inner sphere is equal to $\frac{Q}{R}$, and that of the outer shell, to $\frac{Q}{R^1}$. The larger sphere has the same quantity of charge, but at a lesser potential, the latter varying as the quantity divided by the radius.

The potential, V, of the whole jar is made up of two parts, the positive potential of the inner sphere, $V = +\frac{Q}{R}$, and the negative potential of the outer shell, $V^1 = -\frac{Q}{R^1}$. The combined potential $V = \frac{Q}{R} - \frac{Q}{R^1}$, $V = \frac{Q(R^1 - R)}{R\,R^1}$, or $Q = \frac{V\,R\,R^1}{R^1 - R}$.

Thus far we have found an expression for the difference in potential between the outer and inner coats of a Leyden jar of complete spheric shape, the thickness of whose dielectric is $R^1 - R$. R^1 is the radius of the outer armature, and R the radius of the inner sphere, and Q, the quantity of electricity which is found as a positive charge upon the inner armature, or as a negative charge upon the outer armature. Suppose the Leyden jar to consist of two complete concentric spheres, as in the diagram (Fig. 181), then the charge is $Q = \frac{V\,R\,R^1}{R^1 - R}$, and if R and R^1 are nearly equal, as they usually are, $Q = \frac{V\,R^2}{t}$, t being the thickness of the dielectric.

The ordinary Leyden jar or other condenser does not, however, consist of two concentric spheres, but of two metal surfaces of appropriate shape, separated by a dielectric, and the formulæ in this case are:

The Charge of a Condenser

$Q = \frac{V\,S}{4 \times 3.1416 \times t}$ where S is the surface area of the dielectric.

The Potential of a Condenser

$$V = \frac{Q \times 4 \times 3.1416 \times t}{S}.$$

The Capacity of a Condenser

This is the quantity of electricity required to charge it to a potential of one volt. Calling C the capacity,

$$C = \frac{S}{4 \times 3.1416 \times t}.$$

If a number, *n*, of condensers of the same size are joined in surface, the combined capacity is the number *n* times that of a single couple. They correspond to one large condenser with *n* times the surface, but with the same thickness of dielectric.

If *n* condensers of the same size are connected in series, they correspond to a single couple with the original surface of one condenser, but with a dielectric *n* times as thick. Their combined capacity is, therefore, *n* times as small as that of one condenser.

The capacity of a condenser of glass 1 millimeter thick and with a total coated surface of 1 square meter is $\frac{1}{55}$ microfarad. The capacity of other condensers of different surface or different thickness of dielectric, or with a different dielectric, can readily be calculated. The capacity varies directly as the surface and the inductive capacity, and inversely as the thickness of the dielectric.

SPECIFIC INDUCTIVE CAPACITIES.—(*Gordon and Silow.*)

Air, 1.0	Turpentine, 2.16
Glass, 3.013 to 3.258	Petroleum, 2.03 to 2.07
Ebonite, 2.284	Bisulphid of carbon, 1.81
Gutta-percha, 2.462	Vacuum, 0.9994 (Boltzmann)
India-rubber, 2.220 to 2.497	Hydrogen, 0.9997 (Boltzmann)
Paraffin (solid), 1.9936	Carbonic-acid gas, 1.0003 (Boltzmann)
Shellac, 2.74	Carbonic-acid gas, 1.0008 (Ayrton and Perry)
Sulphur, 2.58	Sulphur dioxid, 1.0037

The experiment of the dissected Leyden jar shows that the two opposite charges are held upon the surface of the glass, even if the outer metal coat or armature is removed and freely handled, and the same thing is subsequently done with the inner armature. Certainly no charge remains on the metal, but the moment the metal coats are replaced, the Leyden jar may be discharged by touching both armatures at the same time. The armatures and the discharging rod form a metal conductor from the charge upon one surface of the glass to that upon the other surface.

Air forms an excellent dielectric for a condenser, and is used for that purpose in some types of high-frequency apparatus. Its utility is greatly increased when under pressure, since air then becomes a better insulator, and disruptive discharges and effluvia are prevented.

Practical Utility of Condensers.—It is seldom that any practical use is made of the experiment in which a Leyden jar may receive a charge and then be disconnected from the generator and retain its charge until a conducting path is brought near enough to both armatures to permit of a disruptive discharge.

When this disruptive discharge takes place over the greatest striking distance, the condenser loses all but $\frac{2}{13}$ of its charge. The residual charge may be discharged in the same way by bringing the discharging rod nearer to the two armatures. And again there remains a small residue. A series of sparks may, therefore, be obtained until finally the discharging rod must be placed in actual contact with both armatures absolutely to discharge the condenser.

Surging of Electricity Into and Out of a Condenser.—The function of a condenser is usually to act as a reservoir into which electricity is forced at periods of increased pressure in a circuit, and from which it flows into the circuit again at periods of low pressure. The double bulb of a continuous current syringe or atomizer furnishes a partial analogy. In that case the pressure of the hand exerted in squeezing the first bulb causes the second bulb to expand and receive a portion of the air or liquid which would otherwise be forced through the tube. When the pressure is relaxed, the pressure thus produced in the second bulb forces its air or liquid into the tube again, and there are generally valves to direct it in the direction of the current flow. The object in the case of the syringe is to secure a uniform instead of a pulsatile flow, and this is accomplished by suitable regulation of the size and elasticity of the second bulb. It must not completely empty itself before the next compression of the first bulb.

The condenser in an electric apparatus receives its charge under extra pressure just like the second bulb of a syringe, but it gives up the charge a great deal more promptly—in fact, almost instantaneously—upon the reduction in tension in the circuit. The condenser becomes discharged before the period of low pressure is finished, and the tension is, therefore, not rendered uniform. Another difference is that the valve-like action of the interrupter stops the current in the original direction, and the current due to the high pressure in the condenser and the low pressure in the circuit is compelled to follow a direction the reverse of that of the original current. Thus the charge during a period of high potential rushes into the large capacity and insignificant resistance of the condenser only to surge out again during a period of low potential in the circuit.

The connections of the condenser with the circuit are not made and broken during this operation. The condenser terminals may even be soldered to those of the battery circuit. The making and breaking of the circuit by the interrupter do not occur on any line leading to or from the condenser, but the interrupter and the condenser are in shunt to each other. Electricity passes through the primary coil and the interrupter when the latter is closed, but has to take the other path and surge into the condenser when the interrupter is opened and the high-tension extra current is induced in the primary coil.

The Capacity of Circuits.—While condensers have very great capacity in a small space, every conductor of electricity has a certain capacity which must be filled as a preparation for the transmission of a current. This is shown in regard to low-tension currents in the case of the very long wire used in telegraphy, where an impulse requires an appreciable time to charge and discharge the wire. This limits the rapidity with which the signals can be sent. They are not instantaneous. After the wire has been charged by pressing the key and thus connecting the wire with the battery, the current will flow uniformly as long as the key is depressed. On releasing the key the wire assumes the condition of a capacity charged to a certain potential, and has a tendency to lose its charge in both directions. The only path ordinarily available is at a distal point, and so all the current commonly flows in that direction, but there is the same pressure in all directions. There does not appear to be anything which could be called electric momentum. If a current continues to flow in a given direction, it is because of a continued pressure or difference in potential, and the current will not continue to flow for an instant at any point in a direction contrary to the pressure at that point. Take a long wire (Fig. 183) starting from the positive pole of a battery whose negative pole is grounded, let this wire have a key for turning the current on and off near the battery, and let it run to a telegraph receiver near the other end of the line and beyond that be grounded. When the key is turned, a current passes through the wire and telegraph instrument to the ground, and, of course, returns through the ground to the negative pole of the battery. If the key is lifted and the electromotive force of the battery is cut off from the wire, there is no piling up of electricity in the distal part of the wire, leaving no charge in the proximal part, as would tend to be the case if water were flowing rapidly through an inclined tube and a stop-cock were turned at the top (K^1, Fig. 184). In the latter case the inertia of the water would create a minus pressure near the stop-cock K^1. Nothing analogous occurs in the case of electricity. Looking at the other end of the wire, suppose the key near the battery is kept turned on all the time, but there is a key near the telegraph receiver. If this key is turned off, there is ordinarily no continued onward pressure of electricity, as there would be of water in Fig. 184 if the stop-cock K^2 at the lower end of the inclined tube were turned off. In the case of water, the motion into the lowest part of the tube would continue in spite of a developing adverse pressure. This pressure is great enough sometimes momentarily to carry the water in the stand-pipe, P, to a higher level than that of the original reservoir. In the hydraulic ram the inertia of a body of water falling through a vertical pipe, and arrested at the bottom at intervals, is used automatically to compress air and force water to a much higher level than that of the water in the reservoir. A liquid or any solid body in motion acquires a momentum which will produce a certain pressure at the point of impact if it be suddenly

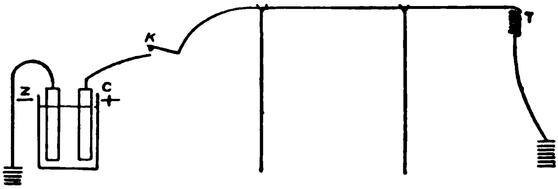

Fig. 183.—Battery and telegraph wire illustrating capacity of the latter.

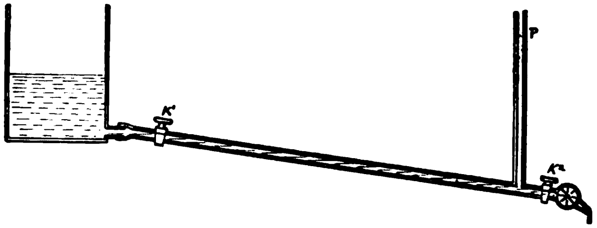

Fig. 184.—Inertia of water flowing through an inclined tube.

arrested by some obstacle. The pressure is momentary, and is very great if the weight of the moving body and its velocity are both great. It may be so applied as to impart the same velocity to an equal mass or to impart a greater velocity to a smaller mass or a less velocity to a greater mass of matter.

An electric current flowing through a short straight wire and suddenly arrested produces no such effect, nor should we expect it to when we consider the imponderable nature and the double directional character of the changes in a material path which constitute a so-called electric current.

The extra current with its spark at the interrupter, when the primary circuit of an induction coil is broken, does not indicate the existence of electric momentum, but is produced by induction.

The condenser action in the case of the Atlantic cable results in its taking two-tenth second before the first trace of a signal is received at the other end, and the full strength of the current not being registered until three seconds later. An expert operator can send about twenty words a minute. There are some most wonderful facts in regard to electric transmission, one being that a voltaic cell consisting of a percussion cap filled with dilute acid into which a zinc rod is dipped can send a signal across the Atlantic. Much stronger currents, of course, are usually employed.

ELECTROLYSIS

This is a chemic change of decomposition which often takes place in bodies through which a current of electricity passes.

The **products of electric decomposition** are called *ions*. *Cations* or *kathions* or *kations* appear at the negative electrode or *cathode*, and anions at the positive electrode or *anode*. Fig. 185 shows the classic experiment of passing a current of electricity through water, slightly acidulated to render it a good conductor, between platinum electrodes. The two inverted glass tubes over the electrodes are completely filled with water and open freely into the common trough of water below. When the current from a battery or other generator yields a potential of 1½ volts or over, as the electric current flows through the liquid, bubbles of hydrogen gas form at the negative electrode, and rise to the top of the tube, where they soon form an appreciable volume of gas. Oxygen gas is liberated in the same way, and fills the top of the tube containing the positive electrode. A certain portion of the water has been decomposed into its constituent elements, and it contains twice as much hydrogen as oxygen by volume. We find an indication of this in the fact that about twice as large a volume of hydrogen gas collects over the negative as of oxygen gas over the positive electrode. The proportions are not exactly two to one, because hydrogen is more absorbable both by the metallic surface of the electrode and also by the water through which it bubbles.

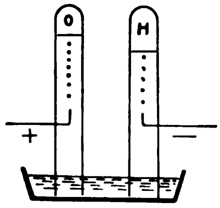

Fig. 185 —Electrolysis of water.

Under uniform conditions the quantity of either gas, preferably hydrogen, will give an accurate measure of the amount of electricity which has flowed through the apparatus.

The voltameter is an instrument for measuring the quantity of electricity which flows through an apparatus by noting the amount of chemic decomposition produced. The simple product which is measured may be a gas, as in the case of the water voltameter, or it may be a metallic element, as in the case of the silver voltameter. In this instrument the positive electrode is of silver, the electrolyte a solution of silver nitrate of a standard strength, and the negative electrode a sheet of platinum. During the passage of the current metallic silver is deposited as a silver-plating upon the negative platinum electrode, and dissolved away from the positive silver electrode. The platinum having been accurately weighed before and after use, its increase in weight shows the amount of silver which has been deposited or separated from its combination with nitric acid. Within reasonable limits the amount of silver so deposited indicates the quantity of electricity which has flowed through the meter, *i. e.*, the number of coulombs irrespective of the rate of flow. One coulomb of electricity will deposit 0.001118 gram of silver. A current of 1 ampere is a current flowing at the rate of 1 coulomb per second, and will deposit 0.001118 gram of silver per second. This is at the rate of about 1 grain a minute (English weight). A current of 1 milliampere would require a thousand seconds to deposit the same 0.001118 gram of silver.

The copper voltameter has two copper electrodes and a 10 per cent. cupric sulphate solution as an electrolyte. It is accurate to within a fraction of 1 per cent., and was formerly extensively used in measuring the electric-light current and determining the amount to be charged by the company for the use of the current.

A voltameter gives correct readings only with a direct current and with a certain strength of current. In the case of the copper voltameter, this corresponds to a current density of about 0.01 ampere per square centimeter of cathode. The voltameter is, for economy of power, placed in shunt, so that only a definite fraction of the current passes through it. The size of the cell and its electrodes varies somewhat with the strength of the current which is to be used, although a wide range may be obtained from a single voltameter by varying the multiplying power of the shunt. In this way the same weight of copper deposited and, of course, the same quantity of electricity passed through the voltameter indicate the consumption of a large or a small amount of current, depending upon the shunt. The multiplying power of the latter must be known to make the voltameter of any value at all.

The voltameter finds its chief utility in the case of a direct current having always approximately the same strength or amperage and the same potential or voltage when it is being used at all. The voltameter gives the total quantity of electricity which has flowed since the last reading was made, and gives a total of all the short or long periods that a stronger or a weaker current has been turned on.

An amperemeter would not give this information unless there were some one there to note the strength of the current, and how long it was turned on each time, and later to calculate the average strength of the current and the total time during which it had flowed.

The meters in commercial use at the present time are mostly based upon the magnetic effect of the current, and are of the nature of clockwork run by an electric motor. This has the advantage that it may be constructed to measure either alternating or direct currents, and that its readings are directly visible upon a dial on the outside of the meter.

Reversible Electrolytic Cells.—In practically every case when a current of electricity has been passed through an electrolyte, if the electrodes are disconnected from the battery and connected with a galvanometer, this instrument will be deflected. It will indicate the presence of a current in the opposite direction to the battery current which has previously been flowing. This current is due to chemic changes taking place at the surface of the electrodes and in the electrolyte which are the reverse of those previously produced by the battery current. A storage-cell or accumulator affords the best example of reversed electromotive force in an electrolytic cell. The most sensitive test which may be applied to a substance with a view to determining whether it is an electrolyte or not is first to run a battery current through it between platinum electrodes, and then see whether it shows reversed electromotive force.

Passing an electric current through an electrolyte between electrodes of any kind produces substances at the two electrodes which form the elements of a voltaic battery, and are ready to generate a reverse current the moment the exciting electromotive force is removed. The products of the electric decomposition are often one or both of them gaseous, and only in small part stored up at the electrodes. The reverse current in such cases lasts only a short time. The storage-battery, on the contrary, produces solid compounds at the electrodes during the passage of the charging current and the cell, after disconnection from the charging currents, acts in every respect like a most efficient voltaic cell.

The counterelectromotive force of an electrolytic cell is present during the passage of the primary current through it. Two observations illustrate this fact. A portable x-ray outfit may be run by a storage-battery charged from a dynamo operated by a belt from a bicycle fastened upon a suitable support. A man has to work very hard to keep the bicycle pedals going and the dynamo revolving, and the charging current flowing through the storage-cells against the counterelectromotive force developed in the latter. The power required to turn the pedals of the bicycle while charging six cells at once is so great that one man can hardly keep at work more than fifteen minutes at a time, and must then be relieved by another man. Thus the work goes on and off for ten or twelve hours. Where the electric-light current is available, the same amount of power is consumed.

Another observation on the counterelectromotive force present during electrolysis is that water is not perceptibly decomposed into hydrogen and oxygen unless a tension of 1½ or 2 volts is applied. A smaller voltage will cause a current to pass through an electrolyte, such as acidulated water, but the water acts as an ordinary conductor, and not as an electrolyte, unless the applied electromotive force is greater than the counterelectromotive force generated by the products formed at the electrodes by the current. The power required to send a weak current of electricity through a conductor is not sufficient also to generate the fixed and definite power of about 1½ volts electromotive force, which is the ordinary counterelectromotive force of an electrolytic cell. If this force is exceeded, however, we shall not only have a current flowing through the electrolyte, but also chemic changes apparent at the two electrodes. These changes are opposite to those which tend to be produced at the electrodes, and which will be produced there the moment the electrolytic cell is disconnected from the exciting electromotive force. The voltage required for the electrolization of acidulated water varies from 1.475 volts with platinized platinum electrodes, to an extreme of 2.48 volts with a polished platinum anode and a mercury cathode.

An **electrolyte** is a substance which undergoes decomposition when an electric current is passed through it. The decomposition may consist in a separation of the substance into its elements, as in the case of water, which is separated into hydrogen and oxygen; or in the separation of a highly complex body into simpler compounds. The electrolytes commonly spoken of are aqueous solutions, but some gases, non-aqueous solutions, and solids or melted solids are electrolytes.

Faraday's laws are:

1. The amount of any substance liberated by electrolysis is proportional to the quantity of electricity which has passed through the electrolytic cell.
2. The amounts of different substances liberated by the same quantity of electricity are proportional to their chemic equivalent weights.

According to the first law, the amount of chemic change is dependent on the quantity of electricity, irrespective of its rate of flow. A current of 5 amperes will effect as great an amount of chemic change in one minute as a current of $\frac{1}{10}$ ampere in fifty minutes. As far as electrolysis is concerned, the coulomb is a more direct electric unit than the ampere. The latter, the ampere, signifies a current at the rate of one coulomb a second. In electrolysis one coulomb does a certain amount of work regardless of whether it takes a second or a hundred seconds to do it.

The **electrochemic equivalent** of a substance is the weight of that substance which will be separated from its chemic combination by 1 coulomb of electricity. The electrochemic equivalent of silver is 0.0011175 gram.

By Faraday's second law the electrochemic equivalent of any other substance may be calculated from a knowledge of the electrochemic equivalent of silver and the chemic equivalents of silver and the other substance. The chemic equivalents are based upon the atomic weights and the valences of the substances. Silver, for instance, has an atomic weight of 107.93, and being univalent, its chemic equivalent is also 107.93. Oxygen has an atomic weight of 16, but is divalent, and consequently its chemic equivalent is 8. The electrochemic equivalent of oxygen is $\frac{8}{107.93}$, that of silver, or 0.00008283 gram. This is the amount of oxygen liberated by each coulomb of electricity when water or any other compound of oxygen is electrolyzed.

An atom or a molecule of any substance is an almost inconceivably small body, but the same proportions hold good for measurable amounts of the different substances when forming chemic compounds. *One gram of hydrogen,* a univalent element with an atomic weight of 1.008, will combine with 8 *grams of oxygen,* a divalent substance, with an atomic weight of 16, to form water. Or, 103.46 grams of lead, a divalent substance of an atomic weight of 206.92, may replace 1 gram of hydrogen in completely combining with 8 grams of oxygen. The gram equivalent of lead is, therefore, 103.46.

Faraday's first and second laws are both embraced in the statement that the same quantity of electricity is required to liberate a gram equivalent of any substance. This quantity of electricity is found to be 96,600 coulombs, and is called a *faraday.*

One **faraday** is the amount of electricity required to liberate one gram equivalent of any substance, and is equal to 96,600 coulombs. It is equal to the amount of electricity carried by a current of 1 ampere in 96,600 seconds, or twenty-six hours and fifty minutes.

The following are the gram equivalents, equal to the number of grams of the different substances liberated by 1 faraday, or 96,600 coulombs:

Of hydrogen	1.008
" potassium	39.140
" sodium	23.050
" ammonium (NH_4)	18.070
" silver	107.930
" oxygen	1.000

The electrochemic equivalents of the same substances, or the number of grams liberated by 1 coulomb, are:

Of hydrogen	104.3×10^{-7}	(*i. e.*, $\frac{104.3}{10\times10\times10\times10\times10\times10\times10}$)
" potassium	4053.0 "	
" sodium	2387.0 "	
" ammonium (NH_4)	1871.0 "	
" silver	11175.0 "	
" oxygen	828.3 "	

ELECTROCHEMIC EQUIVALENTS

1	2 Atomic Weight.	3 Valence.*	4 Chemic Equivalent.	5 Electrochemic Equivalent (Grams per Coulomb).
Electropositive:				z.
Hydrogen	1.0	1	1.0	0.0000105
Potassium	39.1	1	39.1	0.0004105
Sodium	23.0	1	23.0	0.0002415
Gold	196.6	3	65.5	0.0006875
Silver	108.0	1	108.0	0.0011340†
Copper (cupric)	63.0	2	31.5	0.0003307
" (cuprous)	63.0	1	63.0	0.0006615
Mercury (mercuric)	200.0	2	100.0	0.0010500
" (mercurous)	200.0	1	200.0	0.0021000
Tin (stannic)	118.0	4	29.5	0.0003097
" (stannous)	118.0	2	59.0	0.0006195
Iron (ferric)	56.0	4	14.0	0.0001470
" (ferrous)	56.0	2	28.0	0.0002940
Nickel	59.0	2	29.5	0.0003097
Zinc	65.0	2	32.5	0.0003412
Lead	207.0	2	103.5	0.0010867
Aluminum	27.4	2	13.7	0.0001438
Electronegative:				
Oxygen	16.0	2	8.0	0.0000840
Chlorin	35.5	1	35.5	0.0003727
Iodin	127.0	1	127.0	0.0013335
Bromin	80.0	1	80.0	0.0008400
Nitrogen	14.0	3	4.3	0.0000490

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* The electrochemic equivalent in grams per C.G.S. unit, or, $Z=10$ times z, because a coulomb $=\frac{1}{10}$ of the C.G.S. unit of quantity. Atomic weight is the weight of the atom taking hydrogen as 1. Valence is the number of hydrogen atoms it replaces.

† 0.001118, Lord Rayleigh.

Cations are the hypothetic charged particles which travel through the electrolyte in the direction of the current, and are liberated at the cathode; they include all the metals and hydrogen. Anions include chlorin, bromin, iodin, fluorin, NO_3, SO_4, and acid radicles and OH.

Electrolytes are often aqueous solutions of salts, but some other substances are found to be decomposed, usually to a less degree.

An atom of silver carries the same electric charge or transfers the same amount of electricity as an atom of hydrogen.

Grotthuss' hypothesis of electrolysis is that the molecules of a dissolved compound form a chain, and that under the influence of the electromotive force they exchange partners in such a way as to leave a free atom of one substance at one end and of the other substance at the other. Thus in the electrolysis of hydrochloric acid the molecules form such a chain as this:

$$(HCl)\quad (HCl)\quad (HCl)\quad (HCl),$$

but under the influence of the electric current this becomes

$$H\quad (ClH)\quad (ClH)\quad (ClH)\quad Cl.$$

Clausius' Theory of Electrolysis.—This is that salt molecules in solution occasionally dissociate into a positively and a negatively charged portion, *i. e.*, positive and negative ions. The cations move in a general direction from the anode to the cathode, while the anions move in the opposite direction. Those ions which reach the respective electrodes give up their charge there, and also form a free mass of a simpler substance, either as a gas or as a metallic deposit, or as an acid radicle combining with the substance of the electrode, as the case may be. Not all the cations or anions reach the respective electrodes. Very many of them encounter oppositely charged ions and become neutralized. Decomposition and recomposition of the molecules are continually going on, with a resulting uniform drift of oppositely charged ions toward the two electrodes. This dissociation, or the formation of ions, is not necessarily the result of the electric current, but is present whether or not there is any current. Their *motion*, however, is a result of the electromotive force.

The Electron Theory of Electricity.—Observations upon electrolysis in liquids and upon the ionization of gases show that the negatively charged particles in a gas are only $\frac{1}{1000}$ the size of a hydrogen atom. Positively charged bodies as small as this are not known to occur, and so a theory has arisen that there is only one kind of electricity. This is the kind termed *negative*, purely by convention, and it is assumed to exist in unit charges or atoms of electricity called electrons. A negatively charged body is one containing an excess of electrons, a positively charged body, a deficit, and in a neutral body the electrons are in equilibrium.

This theory, which is rapidly becoming the accepted one, regards electricity as consisting of material particles a great deal smaller than the atoms known in chemistry. Each electron carries a charge of about 1.34×10^{-10} coulombs. It requires 9×10^{23} electrons to carry one faraday of electricity. With univalent negative ions, such as chlorin, each charged atom or ion has one electron. This adds 0.001 to the mass or weight of the atom of chlorin, which is 35.4 (times the weight of a hydrogen atom), and makes the chlorion weigh 35.401. The following formula illustrates the use of the symbols that have been adopted for expressing the fact that an atom of chlorin plus a negative charge equals a chlorion or negative chlorin ion:

$$\mathrm{Cl} + \ominus = \overset{-}{\mathrm{Cl}}$$

In the same way— $\mathrm{Na} + \oplus = \overset{+}{\mathrm{Na}}$ signifies that an atom of sodium plus a positive charge equals a sodion, or a positively charged sodium ion. A positive charge subtracts the weight of an electron from the weight of an uncharged sodium atom. The weight added to one set of atoms in electrolysis or in a voltaic cell is exactly equal to that subtracted from the oppositely charged atoms.

Arrhenius propounded in 1887 the theory that a salt whose solution is an electrolyte becomes largely or in some cases completely dissociated into positive ions of one substance and negative ions of the other. This dissociation occurs as the result of the chemic process of solution, and does not require the application of an electromotive force, though the ions are governed by such a force if it is applied. In a voltaic cell, at the electropositive element or the one which is dissolved by the acid positively charged ions of the metal are produced, while the plate itself receives an equal negative charge. The opposite charges produced in this way in the two electrodes are the source of the electromotive force.

Arrhenius' Theory.—This has to do with the solution pressure and the osmotic pressure of substances, and their relation to the degree of ionization in an electrolyte.

A solution of sugar in water may be placed in a semiporous jar which is closed except for its connection with a pressure guage, the jar being placed in an outer jar of water. The "semiporous" jar permits the passage of water, but not of the dissolved sugar, through its pores. It may be made, for example, by taking an unglazed porcelain jar filled with a solution of sulphate of copper and placed in a jar containing a solution of potassium ferrocyanid. This results in copper ferrocyanid being deposited in the pores of the jar, which gives the jar the "semipermeable" character above described. Any soluble substance has a tendency to expand and occupy the whole of the solvent (the dissolving liquid). Adding water to a jar half full of a solution of sugar, the sugar molecules will distribute themselves through the newly added water, and in a certain time the entire quantity of water will contain a sugar solution of uniform strength. Similarly, sugar added to a certain quantity of water will diffuse itself uniformly through every portion of the water, whether or not the water already contains some dissolved sugar. The rapidity with which the sugar dissolves diminishes progressively, and a point is reached when that amount of water will not dissolve any more sugar. The solution is then said to be saturated.

Returning now to the solution of sugar inside of the semipermeable jar surrounded by an outer jar of water: in consequence of the tendency for the sugar to diffuse itself through the largest possible amount of water, since the sugar cannot pass through the wall of the jar, the water from the outside will pass through the semiporous jar and form a uniform solution of sugar inside the jar. The entrance of water increases the pressure inside of the jar as registered upon the guage, and this pressure must be overcome in order that more water may enter. The final pressure attained is that which produces an equilibrium between the attraction impelling the water to enter the jar containing the sugar and the mechanic pressure inside the jar.

The apparatus which has just been described is an *osmometer*, and the force exerted by a soluble substance in drawing the solvent or the dissolving liquid to itself is called the *osmotic pressure* of the soluble substance.

Van't Hoff was the discoverer of the fact that substances in solution behave like gases, and generally are governed by the same laws. Just as gas molecules distribute themselves uniformly throughout any space that is open to them, so the molecules of a soluble substance distribute themselves uniformly through all parts of the solvent.

Boyle's law is that the volume of the same quantity of any gas varies inversely as the pressure is generally applicable to dissolved bodies. Their osmotic pressure usually varies inversely as the volume of liquid in which they are dissolved.

Avogadro's law that under similar conditions of temperature and pressure *equal volumes of all gases contain equal numbers of molecules* is also generally true of dissolved substances.

Van't Hoff noted, however, certain exceptions to the application of these two laws in the cases of soluble substances, and found that for any particular substance there was a fixed and definite ratio between the observed osmotic pressure and the osmotic pressure calculated according to the laws of gases. Van't Hoff's factor is:

$$i = \frac{\text{Observed osmotic pressure}}{\text{Osmotic pressure calculated from law of gases.}}$$

Arrhenius' discovery consisted in the fact that the substances in which Van't Hoff's factor is greater than one are all electrolytes, and his theory offers the following explanation:

Take a solution of a certain strength of some substance, KCl, for example, and calculate the osmotic pressure from Avogadro's law, and using the ordinary chemic formula for the molecule. Now suppose that out of every 100 molecules 86 are dissociated into $\overset{+}{\mathrm{K}}$ and $\overset{-}{\mathrm{Cl}}$, or positively charged free particles of potassium, and negatively charged free particles of chlorin. The amount of substance which, in the first case supposed, would consist of 100 free particles, each being a molecule of KCl, would, in the second case, which Arrhenius' theory presents as the actual condition, consist of 14 molecules of KCl and 86 $\overset{+}{\mathrm{K}}$ and 86 $\overset{-}{\mathrm{Cl}}$ (86 positively charged atoms of potassium and 86 negatively charged atoms of chlorin), or 186 free particles in all. Arrhenius' theory is that these free particles behave like 186 molecules of a gas, and that hence the osmotic pressure of such a solution should be 1.86 times the osmotic pressure calculated from the ordinary molecular formula.

Conversely, taking the ratio between the measured osmotic pressure of a solution and the osmotic pressure calculated from the ordinary molecular formula, we may calculate the percentage of its molecules which are dissociated or its degree of ionization.

The conductivity of a liquid is in a general way proportionate to its degree of ionization. A solution of cane-sugar in water presents practically the same actual osmotic pressure as the osmotic pressure calculated from its molecular formula $C_{12}H_{22}O_{11}$, and, therefore, according to Arrhenius' theory, contains practically no dissociated molecules or ions, and should, accordingly, be a non-conductor of electricity. The latter proves to be the case.

According to this theory, there are many cases in which a salt becomes in great part dissociated by being merely dissolved in water. But this dissociation is into ions or charged particles of two substances, and their properties may be quite different from those of the separate substances themselves. The separate substances, elements in some cases, appear only when the charged particles or ions give up their charge. There is a very great similarity between the chemic processes and the physical effect in an electrolytic cell and in a voltaic cell, the only essential difference being that the processes are reversed. The chemic formulæ representing the reaction taking place while charging a storage-cell by means of a dynamo are simply reversed when the storage-cell is being discharged. At first it is acting as an electrolytic cell, and, in the second case, it acts as a voltaic cell.

In either case the current is produced by the motion of cations in one direction and anions in the other direction; and *the current* is said (purely by convention) to take the direction of the cations. The motion of the cations carrying a positive charge to the cathode produces a "current" in exactly the same way as the motion of the anions carrying a negative charge to the anode. One motion might just as well have been called the direction of the current as the other, except for the fact that in the very beginning the name *positive* had been given to the kind of static electricity which still bears that name; and, of course, the whole electric nomenclature must be harmonious.

The Mechanism of Electrolysis.—Several important facts have been observed. The current strength is the same at every cross-section of a simple or undivided circuit. In the case of a voltaic cell whose two poles are connected by an outside wire the same number of amperes of current flow through the wire and at the surface of either electrode and through the electrolyte. The current density, however, varies according to the size of the cross-section at any part of the circuit, since the same quantity of electricity flows at each cross-section at the same rate. This is equally true in the case of an electrolytic cell, and even when several voltaic cells and electrolytic cells and simple conductors are connected in a simple circuit, *i. e.*, in series, not in parallel or in shunt.

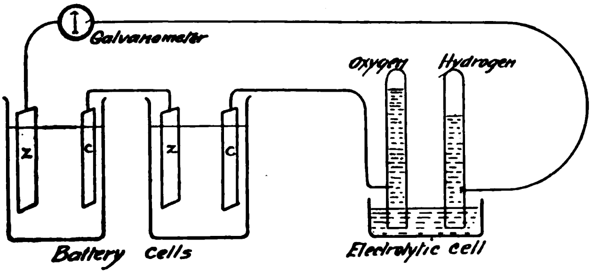

Fig. 186.—Voltaic cells operating an electrolytic cell.

Fig. 186 shows two voltaic cells connected in series with an electrolytic cell in which water is being decomposed into oxygen and hydrogen, a galvanometer, and the necessary conducting cords. The same current strength measured in amperes would be found to be flowing through the electrolyte in either voltaic cell, through any part of the conducting cords, through the galvanometer, and through the electrolytic cell. Even in the latter the same current strength is found in the narrow column of fluid between the electrode and the general trough of fluid, and in this larger mass of fluid.

The products of electrolysis appear only at the electrodes. In the electrolytic cell in Fig. 186 bubbles of hydrogen gas appear at the surface of one electrode and of oxygen gas at the other, but no bubbles of either gas are seen in the liquid between the two electrodes. Chemic tests would not reveal the presence of free oxygen or hydrogen except at the electrodes, and in the liquid and in the air-space above the electrodes into which the bubbles of gas rise. A striking illustration of this fact is presented by the pole detector (p. 207), in which the current passes through a liquid which contains a dissolved substance which is colored red by the free element which is produced at the negative electrode. The red color is seen only at the negative electrode, not at the positive electrode, or in the liquid between the two.

This means, according to our accepted theory, that the ions of this substance which are diffused all through the liquid with a general motion from the positive to the negative electrode present the ordinary physical and chemic properties of the substance only when they give up their charge on reaching the negative electrode. A solution is used in the pole detector which does not give a discoloration with the substance liberated at the other pole.

Phoresis.—The passage of an electric current through an electrolyte is accompanied by the transfer of one substance to the positive electrode and of the other substance to the negative electrode. The latter has become familiar in electrotherapeutics as *cataphoresis*.

An experiment of Sir Humphrey Davy demonstrates at the same time the carrying property of the electric current and the fact that the free products are usually demonstrable only at the two electrodes, and not in the intermediate fluid. Three glasses are used (Fig. 187). The glass *a* into which dips the negative electrode contains a solution of sodium sulphate; *b*, the middle glass, contains a dilute syrup of violets, and *c*, the glass connected with the positive electrode, contains water. The glasses *a* and *b* are connected by a moistened fibrous cord of asbestos, and *b* and *c* are connected in the same way. After the electric current has been applied for a certain time, all the sodium sulphate solution will be found to be decomposed, and the soda will be found in the glass into which the negative electrode dips, and all the sulphuric acid will be found to have been carried through the asbestos fibers and the jar of syrup of violets to the glass *c*, into which the positive electrode dips. The syrup of violets in the middle glass shows no change in color, although it is such a delicate reagent that a drop of acid would produce a red color or a drop of alkali a green color in it.

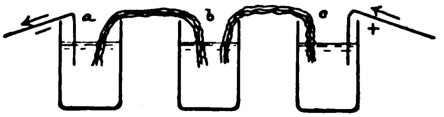

Fig. 187.—Series of electrolytic cells connected by moistened strands of asbestos. Products liberated at extremities only.

The **direction of the phoretic current** is with the electric current, *i. e.*, from the positive to the negative electrode for bases and in the opposite direction for acid radicles.

Two or more electrolytic cells may be connected in series by porous moistened cords, as in Fig. 187, or the liquids may be separated only by porous earthenware partitions. In either case the series of cells acts as a single electrolytic cell of the most perfect type, for, as we have seen, the products of electrolysis are separately collected in the terminal cells whether these products be gaseous, solid, or liquid.

The Human Body an Electrolyte.—The importance of the subject of electrolysis lies in the fact that the human tissues form an electrolyte. The effects of the current are most marked at the electrodes, and in some cases include visible chemic decomposition and phoresis.

Demineralized gelatin is electronegative, and a very slight addition of an electrolyte makes it electropositive. Demineralized gelatin has exceedingly slight conductivity, only $\frac{5}{1,000,000}$, according to D'Héré,[1] and gelatin may be demineralized by electric dialysis.

Two or more electrolytic cells in series, but connected by metallic wires, instead of a porous partition or moistened cord, act as separate electrolytic cells. Each cell in such a case has its own two electrodes, and its electrolyte is decomposed into two simpler substances, without reference to the changes occurring in the other cells. There is practically no mingling of the contents of the different cells, and practically no transference of the contents of one cell to another. The qualifying adverb is used, because even the metallic wires act to a slight extent as electrolytes, and the transmission of a current is accompanied by the passage of ions of metal and other substances through the solid metal. This effect produces no perceptible result in the case of the transmission of an electric current for a few minutes. A case in which it does produce a demonstrable result is the experiment of laying a zinc disk on top of a copper one, and leaving them undisturbed for months or years. The electric current generated by the contact of the two dissimilar metals is a feeble one, but is none the less accompanied by the migration of ions, and at the end of the experiment chemic analysis shows the presence of zinc in the copper disk and of copper in the zinc disk.

The Mechanism of Conduction Through Metals.—According to the accepted *electron theory*, a portion of every metal is normally dissociated into free electrons, which are all negative, and a residue which consists of positively charged ions of the metal. These ions are positively charged simply because they are deficient in the number of negative electrons with which they are associated when in a neutral state. The metallic ions are relatively fixed in position, but the dissociated electrons move freely about among the atoms of metal. When an electromotive force is generated and a positive impulse is applied at one end of the metal and a negative impulse at the other, the dissociated electrons (negative) are driven toward the anode. It is this anionic stream of electrons in a direction opposite to the so-called direction of the electric current which usually constitutes, to a great extent, the means of transmission through a metal. This description refers to the condition in which two wires from the generator of electricity are fastened to the two ends of a piece of metal. The cationic current of positively charged metallic ions toward the cathode is so very slight as to require a long, tedious experiment to demonstrate it, and cannot be regarded as playing a rôle of any importance in the ordinary conduction of electricity through the metal.

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[1] Jour. de Physiol. et de Pathol. génerale, March, 1911, vol. xiii, No. 2, p. 176.

Phenomena at the Electrodes in an Electrolytic Cell.—A. *At the Anode.*—A metal dipped into an electrolyte becomes subject to the force of osmosis. The metallic ions have a strong tendency to dissolve in the liquid if an electric current is passing through the metal toward the liquid. This means that the metal which forms the anode of an electrolytic cell in many cases loses positively charged particles to the electrolyte. These are always of one kind if the anode is of a simple metal, but if it is of an alloy, such as brass, the cations passing into the liquid from the anode may be of one or other metal composing the alloy, according to circumstances. This cationic action is sometimes the sole means of effecting the passage of the current from the anode to the electrolyte. This is the case with the zinc electrode of a voltaic cell, where the amount of current is fully accounted for by the amount of zinc dissolved. This is the effect produced in mercuric and other cataphoresis or anodal diffusion.

In other cases very few ions of the metal anode pass into the electrolyte, and the transmission of the electric current is effected almost entirely by the *discharge of anions* brought by the electrolyte to the surface of the anode. Platinum electrodes are used when it is desired not to have particles of the anode pass into the electrolyte. Platinum ions exist, but they are not readily soluble in the usual electrolytes, such as the dilute acid in a water voltameter or the tissues of the human body in electrolysis or galvanopuncture. The current cannot be carried from platinum to acidulated water by platinum cations to any practical extent. The process taking place at the anode consists almost entirely in the discharge of oxygen anions resulting in the evolution of free oxygen gas and the discharge of free electrons (negative, of course) which enter the platinum anode.

Exceptional ways in which the electric current may pass into the solution from the anode are:

1. Oxidation of a positive ion in the electrolyte.
2. Reduction of a negative ion in the electrolyte.

1. When the current is turned on the change which takes place at a platinum anode immersed in a solution of a ferrous salt, under some circumstances, converts it into a ferric salt. This contains more highly charged cations (positively charged ions which tend to travel through the electrolyte toward the cathode), and consequently involves the transfer of positive electricity from the electrode to the electrolyte. This is done according to the electron theory by the entrance of free electrons into the platinum anode from the electrolyte.

2. On the other hand, if a platinum anode is immersed in a ferrocyanid solution, the passage of the current produces a change to ferricyanid, a negative ion of a lower charge. Here there has been a transfer of a negative charge from the electrolyte to the anode, and this also according to our theory by the passage of free electrons from the electrolyte into the platinum anode.

B. *At the Cathode.*—1. There may be the *discharge of a cation.* In ordinary electroplating the free metal is deposited from the electrolyte upon the surface of the cathode, and the metallic ions (cations) lose their positive charge to the cathode. The latter part of the process, according to the electron theory, means that free electrons (always negative) pass from the cathode into the electrolyte.

2. The *formation of an anion.* This occurs only under exceptional circumstances. Thus, a platinum cathode surrounded by an electro-

lyte kept saturated with chlorin gas will produce a certain number of chlorions or chlorin anions.

The other methods by which the current sometimes passes from the electrolyte to the cathode are also the reverse of those at the anode. They are:

3. Diminution of the positive charge on a cation by chemic reduction.
4. Increase of the negative charge on an anion, by oxidation.

Phenomena Occurring in the Electrolyte.—It is not necessary to assume the presence of free electrons in the electrolyte. There are always equal numbers of cations and anions in the solution. These are traveling in opposite directions, and the sum of the electric charges transferred by them constitutes the total electric current. Ions have different degrees of mobility. If, in a certain case, the cations are moving at ten times the speed of the anions, then ten times as much of the electric current through the electrolyte will be made up of a transfer of a positive charge by the cations as of a negative charge carried by the anions. The current is then said to be mostly cationic.

Speed of Ionic Migration.—The motion of the ions under the influence of an electromotive force is, on the whole, a drifting movement toward either electrode. The individual ions do not traverse the entire distance at a gradually increasing velocity, as they would do if there were only the constant electromotive force to be considered. On the contrary, they move a certain distance and then collide with other ions or molecules and lose their acquired velocity. If they collide with oppositely charged ions, the charges on the two are neutralized, and existence as dissociated ions temporarily ceases. The effective mobility or the average velocity of the ions, including periods of rest, at a potential gradient of 1 volt per centimeter, is in an aqueous solution for—

Copper ions	0.000309	cm. per second
Chlorin ions	0.00058	" " "
CrO_7 ions	0.00047	" " "

This means that chemic changes are propagated through electrolytes at the above velocities. Measurements have been made by Sir Oliver Lodge in the following manner: A glass tube filled with jelly consisting of gelatin water, sodium chlorid, and a little phenolphthalein communicates at one end with a solution of hydrochloric acid. Platinum electrodes are used, and the current passed from the hydrochloric acid into the salt jelly. This produces a migration of hydrogen cations into the jelly, and, as they advance, they decolorize the phenolphthalein. Their rate of progress can, therefore, be measured.

This and similar measurements made with liquid or jelly electrolyte give results at apparent variance with the statement that in electrolysis the free products appear only at the two electrodes, and do not produce demonstrable effects at intermediate points in the electrolyte. The example of the three connected electrolytic cells will be remembered, a middle one containing dilute syrup of violets, one end cell full of water, and the other end cell full of sodium sulphate solution. After the flow of the current all the soda was found in one end cell and all the sulphuric acid in the other, while the violet solution, a very delicate test for acids or alkalis, remained unchanged.

The difference seems to indicate that in the experiment with the sodium chlorid jelly the hydrogen ions collide with chlorin ions which are present to form hydrochloric acid molecules at different points in the electrolyte as the hydrogen ions advance. The free hydrochloric acid thus produced decolorizes the phenolphthalein. In the other experiment the ions of the sulphuric acid radicle advance through the electrolytes in the three jars without forming molecules of free sulphuric acid until the ions reach the anode and lose their electric charge. The ions which have collided with oppositely charged ions have formed free molecules of a salt not of an acid or alkali in the intermediate portions of the electrolyte. Hence the delicate reagent for free acid or free alkali has not been affected.

The Velocity of the Ions in an Electrolyte and in Gases, and of Electrons in Metals.—The figures found by the method described above are astonishingly small compared with the velocity of the ions of a gas—20,000 miles a second in an *x*-ray tube, or, compared with the rate of transmission of electricity by metals, 288,000 miles a second. In the case of metals, however, the transmission is effected not by ionic migration, but by the migration of free electrons.

Conduction by Fused Salts and by Metallic Oxids.—Salts and metallic oxids at ordinary temperatures are very poor conductors of electricity. The former become good conductors if they are melted by heat, and it is very readily demonstrated that their conduction is electrolytic. In fact, this is the method adopted in obtaining some of the rarer metals. Magnesium may be obtained in this way. An ordinary clay tobacco-pipe with an iron wire from the negative pole of the battery passing into it through the stem is filled with a mixture of chlorid of potassium and chlorid of magnesium. The salts are fused by the heat of a Bunsen burner, and a graphite anode from the battery is dipped into the melted mass. The conduction is excellent, and is accompanied by the liberation of chlorin gas at the anode, and of melted metallic magnesium at the iron cathode in the bowl of the pipe.

The comparatively infusible metallic oxids, such as the oxid of zirconium, are made use of in the Nernst lamp. There is a "heater coil" of platinum wire through which the electric current is first passed, and in which sufficient heat is produced by ohmic resistance to bring the "glower," consisting of metallic oxids, to a temperature at which it becomes a conductor of electricity. The current is such a powerful one as to heat the "glower" to brilliant incandescence. The reasons advanced for believing that the excellent conduction developed in the case of oxids of the metals of the alkaline earths by heating them to incandescence is electrolytic are twofold. One reason is that, theoretically, if the conduction were by the motion of free electrons, as in metals, the substance should be opaque, while the oxids in question are transparent. A stronger reason is that when a "glower" consists of a mixture of the oxids of two different earths, one of these is sometimes found to be more concentrated at one pole than at the other.

The Passage of Electricity Through Solids.—This is not so manifestly due to a migration of ions as is the case with a liquid conductor, but the fact that such a migration of atoms does take place, even with very weak currents, was shown by an experiment in which a piece of gold and a piece of copper were left in contact for four years. The weak current produced by the contact of the two dissimilar metals during this long time caused a sufficient migration of ions in each direction thoroughly to saturate the gold with copper and the copper with gold. The ionization of a metal through which electricity is conducted has important therapeutic uses and so does the effect upon the tissues of the animal body. These are essentially liquid, and an important department of electrotherapeutics is concerned with the changes produced in them by the passage of an electric current. This will be considered in another place.

There is always more or less resistance to the passage of a current through a conductor, and this depends partly on the nature of the substance and partly upon its diameter and length. Substances which conduct electricity very well are called conductors; the metals are conductors—some better than others. Substances which conduct electricity so poorly that they are used to prevent its escape from conductors are called non-conductors or insulators—glass, rubber, and gutta-percha are examples.

THE HEATING EFFECT OF THE ELECTRIC CURRENT

A current of electricity passing through a good conductor, such as a copper wire, heats the conductor to a certain extent. This effect is entirely analogous in case of a copper wire to the production of heat by friction in mechanic motion, and in the case of a short straight wire at a distance from any other wire or magnet or magnetizable body, the only electric energy lost by the current in passing through the wire is that which is converted into heat. The conditions expressed in the last sentence show that no work is being done by the current except the simple overcoming of ohmic or frictional resistance in the transmission of power through the wire. In a case of this kind the amount of heat produced depends upon two quantities: the resistance of the conductor measured in ohms and the strength of the current measured in amperes. The amount of heat is expressed in gram-degrees, each unit sufficing to raise the temperature of 1 gram of water 1° C. The following equations give the amount of heat generated in one second by a current of C amperes, with E volts, through a resistance of R ohms.

The amount of heat $= C^2 \times R \times 0.2405$ gram-degrees per second.
The amount of heat $= E \times C \times 0.2405$ gram-degrees per second.

The temperature to which the wire will be raised will be greatest, of course, when this amount of heat is concentrated in a short length of conductor, and also when the conditions prevent the rapid radiation of heat from the conductor. In regard to the last point, an inclosed electric motor becomes hotter than the same identical motor without a case. An example of the first fact is found in the incandescent lamp. The few inches of filament present a resistance of 250 ohms, and become white hot in a second from a current of $\frac{1}{4}$ ampere; while the same $\frac{1}{4}$ ampere current passing through copper wire $\frac{1}{10}$ inch in diameter and 250,000 feet long will encounter the same resistance and generate the same total amount of heat in a second, but without a perceptible elevation in temperature. In fact, in the case of $\frac{1}{10}$ inch copper wire, such as the electric-light service wires, a current of even as much as 5 amperes running all the time will not produce a maximum elevation of over 2° F. in the temperature of the wire.

The heat generated by ohmic resistance to the passage of an electric current is utilized in electrotherapeutics especially in the following ways: first, in making warm or hot compresses; second, for cautery; third, for the diagnostic and therapeutic application of light and radiant heat.

The Temperature Changes in Different Batteries.—These are not always due to the ohmic resistance alone, but may be influenced by the chemic changes which accompany the passage of the current through the medium. A gravity cell, for instance, cools as a result of the electric activity. The same is true of a Daniell cell and of a storage-cell or accumulator during its discharge. The Daniell cell transforms all the chemic energy lost by its materials during the operation of the battery into electric energy, and also about 1 per cent. more. This slight excess of energy produced is abstracted from the latent heat of the battery, which is, therefore, cooled as a whole. Its zinc pole becomes warmer and its copper pole cooler.

The Clark cell, on the contrary, transforms only 74 per cent. of the chemic energy expended into electric energy, the remaining 26 per cent. being transmuted into heat. A cell of this type becomes decidedly warmer during operation.

The Temperature Changes Produced by the Passage of a Current Through Different Electrolytes Outside of the Battery Itself.—These vary just as much as do those in the fluids of a battery in operation. There is always a certain amount of heat due to the ohmic resistance of the liquid. This may be augmented or diminished by the thermal effect of the chemic change induced in the fluid by the passage of the current. Placing a Daniell cell in the circuit of a powerful battery which sends a current through the cell in a direction opposite to that of the current which it tends to generate, we should reverse the chemic processes which normally take place in a Daniell cell. The thermal effect is also reversed, and the cell becomes hotter instead of cooler.

The ordinary process of charging an accumulator or storage-cell by sending a dynamo current through it in a reverse direction also reverses the thermal effect and the cell. With the usual strength of acid a storage-cell cools slightly on discharge, and is warmed slightly when being charged by a current sent through it in the reverse direction. Generally speaking, the thermal effect of the chemic change from passing a current through a liquid is to produce heat if the chemic reaction is such as would ordinarily do so, and to produce a cooling effect if the chemic reaction indicates that heat is rendered latent.

The Heat of Ionization.—An electrochemic equivalent of any substance causes either the absorption or the liberation of a certain number of joules or heat units when it becomes positively or negatively ionized. In the cases in which heat is absorbed at the pole where a certain ion is produced, this usually means that work must be done in order to cause the substance to enter the ionic state. When this is the case, it will usually be found that heat is liberated when the substance leaves the ionic state. Copper is such a substance, and its heat of ionization is +37,200. Zinc behaves in the opposite way: it takes work to bring it out of the ionic state, heat being rendered latent and the temperature falling at the pole where this is taking place. Under the conditions present at the pole where zinc ions are produced the temperature rises because heat is liberated. In entering the ionic state zinc actually performs work in heating up the surrounding medium. Its heat of ionization is −69,500. This means that one electrochemic equivalent of zinc in entering the ionic state loses 69,500 joules of energy in the form of heat.

The heating of liquids (electrolytes or not) by ohmic resistance is one of the disadvantages of the liquid interrupters and rheostats used in electrotherapy.

Examples from outside the domain of electricity illustrate the subject of latent heat. Salt and ice mixed together have a strong tendency to form a solution of salt in water, and this is accompanied by the absorption of a large amount of latent heat. Such a mixture forms a freezing mixture. Water and sulphuric acid have an equally strong tendency to mix and form a solution of sulphuric acid, but in this case the process is accompanied by the liberation of heat.

Anything like a complete discussion of this branch of the subject would carry us too far into the domain of theoretic electrochemistry. It may be added, however, that the forces at work are now thought to be those which produce electromotive force.

The Degree of Ionization May be Determined by Cryoscopy.— Raoult's discovery that the freezing-point of a solution depends upon the number of molecules held in solution was immediately followed by the discovery that solutions of salts and some other compounds gave results corresponding to a greater number of molecules than would be indicated by their chemic formulæ. This has been explained by Arrhenius on his theory of dissociation of ions. He supposes that in every solution the freezing-point depends upon the number of dissolved particles (either entire molecules or dissociated ions formed by the division of molecules). We may then say that one gram-particle[1] (instead of 1 gram-molecule) dissolved in one liter lowers the freezing-point 1.85/100° C. The number of degrees that the freezing-point is lowered (L) divided by 1.85/100°C., will give the number (N) of gram-particles dissolved in a liter of the liquid:

$$N = \frac{L}{1.85}.$$

The number thus found will be the number of gram-particles, both whole molecules and dissociated ions formed by split-up molecules. The number of gram-molecules, N^1 in the substance is known from its molecular formula and the amount or weight of the substance which has been used in making the solution. The number of gram-ions is

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[1] A *gram-equivalent* of any element is the amount of the element which will replace a gram of hydrogen or is equivalent to a gram of hydrogen in chemic combination. It is found by dividing its atomic weight by its valence or the number of hydrogen atoms which each atom will take the place of or combine with.

A gram-equivalent or a gram-molecule of a substance, either simple or compound, is the number of grams represented by its molecular weight.

A normal solution is one containing one gram-equivalent of the substance to the liter. Thus, a gram-equivalent of potassium chlorid, KCl (K, atomic weight 39; Cl, atomic weight 35), weighs 74 grams, and a normal solution of potassium chlorid contains 74 grams of KCl to the liter. A decinormal solution of KCl contains 7.4 grams per liter.

A *gram-molecule* is the same as a gram-equivalent of a substance, and is a quantity of the substance equal to the molecular weight expressed in grams.

A *gram-ion* is the quantity of a substance in the ionic or dissociated condition equal to its chemic equivalent weight expressed in grams.

The number of *gram-particles* of a substance in solution is equal to the sum of the gram-molecules and of the gram-ions of the substance.

equal to the number of gram-particles (N) minus the number of gram-molecules (N^1).

This number of gram-ions is made up of negative and positive ions: very often one of each polarity for each molecule which is broken up, though some molecules split up into a greater number of ions. A molecule of sulphate of copper ($CuSO_4$) splits up into two ions—a positive copper ion ($\overset{+}{Cu}$) and a negative sulphion ($\overset{-}{SO_4}$).

If N^1 is the number of molecules placed in the liquid and a is the coefficient of dissociation, then—

$a\,N^1$ molecules are dissociated.

$N^1 - a\,N^1$ molecules are intact.

If each dissociated molecule yields 2 ions, there will be—

$2\,a\,N^1$ ions.

There are then in solution $N^1 - a\,N^1$ molecules and $2\,a\,N^1$ ions, and their sum is equal to the number of particles found by cryoscopy from a calculation based upon the freezing-point.

The following formula gives a, the coefficient of dissociation:

$$a = \frac{N - N^1}{N^1}.$$

The following is a concrete example. A decinormal solution of $CuSO_4$, or one in which 0.10 gram-molecule (15.9 grams by weight) of $CuSO_4$ is dissolved in 1 liter of water is found to have had its freezing-point lowered 0.23° C. by the addition of this amount of $CuSO_4$. The number of gram-particles calculated from the fact that 1 gram particle in a liter lowers the freezing-point 1.85° C. is found to be 0.12432. Hence—

$$a = \frac{0.1243 - 0.10}{0.10} = 0.243.$$

A calculation based upon the freezing-point shows that in a decinormal solution of $CuSO_4$, 24 per cent. of the molecules become dissociated into ions in the mere process of entering into solution. This agrees very closely with the calculation based upon the conductibility of the solution.

Osmotic pressure, freezing-points, and electric conductivity are all determined by the degree of ionization.

Observations by Maillard,[1] Loeb,[2] Paul and Krönig[3] lead to the belief that the ions in any solution are the active agents in any effect upon living tissues. The effect of antiseptics is due, according to Paul and Krönig, practically entirely to the ions. The degree of ionization of a metal, as in a solution of bichlorid of mercury, may be reduced by adding to the solution ions of some other metal with the same anion (NaCl per ex.), and if the latter are non-toxic, the toxicity of the solution will be reduced. An experiment was made with anthrax culture smears dipped in a solution containing 1 gram-molecule of bichlorid of mercury (this being 270 grams in weight) in 16 liters of water, and the number of spores which survived after an immersion of

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[1] Journal de Physiologie et de Pathologie, 1899, vol. i, p. 651.

[2] Archiv. f. ges. Physiol., 1898, vol. lxix, p. 1.

[3] Zeit. f. physikal. Chemie, 1896.

six minutes was found to be only eight. But if 1 gram-molecule of sodium chlorid, NaCl (weighing 58 grams), was added, 32 spores survived, and the culture showed 32 colonies. With two gram-molecules of sodium chlorid the number of colonies was 124; with 3, it was 284; and with 10, it was 1087. The strength of the mercurial solution was the same in each case.

The absorption of moisture and the interchange of substances in solution through organic tissues which form the basis of animal and vegetable life are all dependent upon the number and properties of ions.

The theory that all life is but a manifestation of electricity is, therefore, not at all an impossible one. The further theory that all matter is of but one substance, either electricity or variously modified by electricity, is one of the picturesque possibilities of the future.

ELECTRICITY OCCURRING IN ANIMALS AND PLANTS

THE differences in potential between portions of the surface of animals or plants which are so generally present are seldom as great as in the electric eel and the torpedo. They generally require special apparatus for their detection, but it is none the less probable that they are of vital importance. Electricity is developed especially in the irritable and contractile tissues, notably the nerves and muscles. The glands and epithelium, among many other structures, manifest it.

Phytolacca electrica, a Brazilian plant said to have been lately discovered, is said to have certain electric properties, and the charge or shock given off by contact with it is claimed to be equal to that of one Daniell cell.

The general law governing the difference in potential between portions of the *surface of a living body* is that it develops only when there is a difference either in the nature or in the activity of the chemic processes taking place in the two regions. When there is a difference in kind, the region where processes of decomposition are in excess is negative to the region where synthetic processes are in excess. If both are regions of decomposition, the one at which the process is most active is negative to the other. And if both are regions of synthesis, the least active is negative to the other.

There is a difference between the electric potential at the two ends of an egg, whether fertilized or not. Ida Hyde[1] has tested this by means of the capillary electrometer, the difference in potential in the pigeon's egg increasing as development progresses. In some other eggs (those of Fundulus) the different stages of segmentation cause rhythmic oscillations and reversals of the direction of the current. The sources of electromotive force are anabolic and alkaline changes in the chromatic mass in repose and catabolic and acid changes in this mass in activity, and variations in viscosity and surface tension.

Delicate electrometric methods have shown that there are electric currents in the eye corresponding to currents of action in the nerves or muscles.[2]

Static charges occur upon different parts of the living body. From muscular contraction or some other vital activity electromotive force is generated, and as the dry skin is a very poor conductor, opposite static charges may be formed on different parts of the surface. Heydweiler[3] has made observations which show that these opposite charges may remain for a relatively long time.

The ganglion-cells of the anterior cornua of the spinal cord have been thought to be sources of electromotive force. Experiments reported by S. Baglioni[4] were made upon a strychnized spinal cord, and showed

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[1] Amer. Journ. of Physiology, vol. xii, p. 241, 1904.

[2] H. Gertz, Centralbl f. Physiologie, vol. xix, July 15, 1905.

[3] Annalen der Physik., No. 5, May 29, 1902.

[4] Centralblatt f. Physiologie, vol. xix, p, 345, August 26, 1905.

that the current of demarcation was very much increased. The inference was that activity of the spinal ganglionic cells is accompanied by electric phenomena of the nerve-trunk.

Electric Currents in the Skin.—Skin may be removed from the body and still retain vital properties, as shown by its survival and growth when used in skin-grafting. As long as the skin is fresh and possesses vitality, it may be shown by appropriate electrodes and meters to possess electric properties. A current will generally pass from an electrode applied to the inner surface of a piece of skin through a conducting wire and meter to an electrode applied to the outer surface. This may be called the current of rest, and in the case of a piece of skin freshly removed from the body, the internal surface is usually positive.

It is necessary to have non-polarizable electrodes, and to be sure that the results actually indicate a difference in potential between the two surfaces of the skin. Without any special precautions it would be easy to have an electric current produced by a difference in the degree or kind of action upon the two electrodes by a difference in them or by the difference in the chemic composition of the moisture upon the external and internal surfaces of the skin. In other words, the skin and the two electrodes might form a miniature voltaic cell unless precautions were taken to prevent such an effect.

Currents Produced by Contact of the Inner and Outer Surfaces of the Skin with Saline Solutions.— These may be detected by the same method as that used by Chanoz in the case of acid solutions. A piece of skin is fastened over the end of a tube filled with the solution, and dipped into another filled with a precisely similar solution. An electric current will often flow through suitable electrodes and conducting wires passing from the liquid in one tube to that in the other. These currents were one of the early discoveries in electrophysiology, and have been experimented upon by DuBois-Reymond, 1848; Rosenthal, 1865; Roeber; Englemann; Hermann; Bach; Oehler; Bayliss; Bradford; Reid; Tallport; Waller, 1901.

Currents Produced by Contact of the Inner and Outer Surfaces of the Skin with Acid Solutions. Chanoz's Observations.—An experiment by Chanoz[1] illustrates the method of detecting bioelectric currents and shows the results obtained with living or dead skin forming a diaphragm between two portions of liquid.

An inverted U-shaped tube, 1 cm. in diameter, is open at one end and closed at the other by a piece of skin held in place by an elastic band. Both ends of the tube dip into vessels of the solution to be tested and the tube is also completely filled with the same solution. Each of the outer vessels is connected by impolarizable electrodes, zinc in a solution of sulphate of zinc, with Lipmann's capillary electrometer. The latter should be of medium sensitiveness and small electric capacity. Carpentier's potentiometer, actuated by two Weston cells, is used for determining the difference in voltage without any calculation.

The piece of skin is taken from a frog which has just been killed, and the experiment performed so quickly that the current is tested in one and one-half minutes after the incision has been made.

The experiment is made to determine the difference in potential between the outer and inner surfaces of skin, when both are exposed to a solution of the same material and the same strength.

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[1] C. R. de l'acad. des Sciences, July 17 and 24, 1905.

Chanoz reports the following results: (1) At the moment of closing the circuit (by the electrode connected with the capillary electrometer) the internal surface of the fresh frog-skin is always positive to the outer surface and the direction of the current is as shown in Fig. 188. (2) The duration of the positive condition varies with different acid solutions. It is soon reduced to zero, changes to a negative condition, and finally becomes zero. When the fluid is a centinormal solution of H_2SO_4, the inner surface of the skin immediately becomes positive, and the change to a negative condition occurs within ten minutes, if at all. With a centinormal solution of HNO_3 the change from a positive to a negative condition occurs in about a minute, and the negative condition lasts for several minutes. (3) A piece of skin no longer presenting a difference in potential after a certain duration of contact with rather a strong solution may be employed for an experiment with a more dilute solution of acid, and will then give a new difference of potential, such as would have been obtained at first with a dilute solution. (4) The frog's skin continues to give electric reactions with acid solutions as long as two or three days after the frog has been killed. Chanoz explains these facts by the theory that strong acids are more powerful stimulants to the skin than weak ones, and change the direction of the current of rest more quickly.

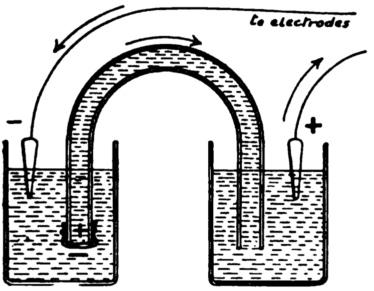

Fig. 188.—Testing cutaneous currents. The current of rest.

Chanoz's interpretation of these facts and of the results reported by other experimenters is as follows:

I. Dead skin (boiled or in alcohol or for a long time in distilled water) does not give electric reactions. These are a property of fresh skin still possessing vital properties.

II. Galeotti has recently found that the inner surface of the skin becomes negative instead of positive with a solution of KNO_3, and that no electric reactions are obtained with solutions of KI, KCl, or KBr. Saline solutions generally cause the inner surface to be positive.

III. Other authors, particularly A. D. Waller (Proceedings of the Royal Society of London, 1901–1902.), have studied the electric reactions of the skin of the frog, cat, and man. They have shown that direct stimulation of the skin leads to a perturbation of the current of rest ordinarily observed.

Skin responds to stimulation by presenting a negative variation, and Waller considers this characteristic of life.

IV. Galeotti does not think these currents a vital phenomenon, but due simply to osmosis; that the skin is a membrane differently permeable to different ions.

To bring about a conformity between this theory and the facts observed by Chanoz it is necessary to assume—(1) That the permeability changes after a certain time, and (2) that it varies with the concentration of the acid in contact with the skin.

The Current of Rest.—When a region of the body is said to be negative to another region, this means that it corresponds to the zinc plate in a voltaic cell, and if a wire is connected with the two portions of the body, an electric current will flow through the wire toward the portion which is "negative to the other." The portion which is negative to the other is a region of lower potential. It is not necessarily charged with negative electricity.

In the tissues themselves the current is continued from the region of decomposition to the region of synthetic activity. D'Arsonval's explanation is that the difference in potential is dependent upon reaction between oxidizable substances in the tissues and the oxygen in the blood plasma. Currents of rest are electric currents the result of the above-described chemic processes, and are continuous and uniform for long periods of time. They present in this respect a striking contrast to the currents of action which develop suddenly in consequence of some irritation, and as rapidly cease to flow. Currents of rest in mucous membranes flow from the excretory surface of the glandular epithelia to the surface where the epithelial cells are in relation with the blood-vessels. If it were practicable to connect an external circuit with these two layers, the current would flow through the wire from the vascular to the secretory surface. The latter corresponds exactly to the zinc pole of a voltaic cell. The current between the layers of a mucous membrane is transmitted mostly by the epithelial cells, and may be called an entrant glandular current. In the skin the current of rest is generally from the internal vascular to the external exfoliating layer. It is, therefore, an emergent current.

There is no current of rest in uninjured nervous or muscular tissue; but whenever such tissue is injured, the damaged portion becomes negative to any uninjured portion. This produces a current of rest which may continue uniform for several hours. It will continue as a current between dying (but not between dead tissues) and uninjured ones.

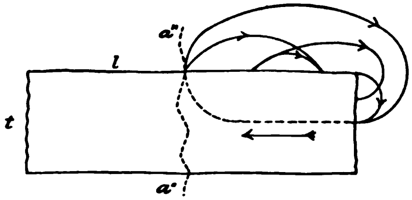

Fig. 189.—Current of rest in muscle or nerve.

The current of rest has long been the subject of demonstration in the case of muscles and nerves in the way shown in Fig. 189. A nerve or a cylindric portion of a muscle in its natural position is divided by two transverse incisions and an external circuit is applied with a delicate measuring instrument. Currents will flow through an external circuit from any point distant from the center of one of the transversely cut surfaces to any point nearer that center. The diagram shows a number of such external circuits with the direction of the current of rest through them. It will be seen that the surface injured by a cut transversely across the muscular or nervous fibers is "negative" to other parts of the muscular or nervous bundle. It is found that each cut end acquires the same "negative" property and in the same degree and that there is an equator a''–a'', by reference to which the polarity of any two points may be determined. The point which is further from the equator in either direction, is negative to a point nearer the equator, and this is true whether the points are on the same or on opposite sides of the equator. Applying the test electrodes to the middle point of each transversely cut surface, at the ends of a muscular cylinder, it will accordingly be found that there is no difference in potential and hence no current.

The insertion of a tendon into the periosteum of a bone corresponds to a transversely cut surface, and accordingly a current of rest is found to exist if impolarizable electrodes are applied near this attachment and to the lateral surface of the muscle or tendon.

Experiments have been made by Bernstein and Tschermak upon the current of rest in muscles to determine whether there is a preexistent difference in potential between the transversely cut surface of a muscle and its longitudinal surface, or whether the difference develops later in consequence of chemic or other *alteration*. Bernstein believes that the current of rest shows its maximum strength immediately. S. Garten[1] thinks he has shown that $\frac{2}{1000}$ or $\frac{8}{1000}$ second elapse before the current develops. And when the muscle is cooled, a period of $\frac{5}{1000}$ second may elapse.

A carefully prepared muscle upon whose longitudinal surface are placed two non-polarizable electrodes wet with Ringer's solution does not give a current of rest (Biedermann). But R. Hober[2] finds that a current of rest develops when the extremity of the muscle is dipped into a solution of potassium chlorid. Other solutions which produce this effect are of salts of lithium, sodium, cesium, ammonium, rubidium, and potassium with the anions C, N, S, NO_3, I, Br, Cl, acetic acid radicle, SO_4, tartaric and citric acid radicles. In each list the last is most favorable to the development of a current in the normal direction; that is, corresponding to a negative condition of the extremity of the muscle.

L. Hermann's experiment was performed by means of a fall-rheotome which makes a section through the muscle simultaneously with its making the contact of an electric signal. The time that may elapse before the development of a current of rest may be the time it takes the injured muscular substance to die; or, according to DuBois-Reymond, it is the time that the semipermeable membrane takes to lose its permeability for the negative ions of the muscular fiber.

I. Bernstein and A. Tschermak[3] have performed the same experiment under more exact conditions with an electric motor and photographic registration, and have shown the presence of a current of rest in an average of $\frac{3}{10,000,000}$ second. This result is more in accord with the theory of the preëxistence of this muscular current than with any theory that a recognizable alteration could occur in such an infinitesimally small period of time.

The axial current in nerves has been studied by E. Hellwig.[4] He considers that its existence is proved by the correspondence between the two segments of a nervous filament. It is an ascending current in the sciatic nerve of the frog, and a descending current in the electric nerve of the torpedo or electric eel. This has all been established by DuBois-Reymond and Mendelssohn. Schultz has studied the relation of the spinal roots to this phenomenon; also the influence of the length of the nerve on the intensity of the axial current, and the negative variation possible in case of stimulation. The important fact is that the axial current is cellulipetal and flows from the ganglion-cell from

[1] Arch. f. d. gesam. Physiologie, vol. cv, p. 291, 1904.
[2] Centralb. f. Physiologie, vol. xviii, p. 499, November, 1904.
[3] Arch. f. d. gesam. Physiologie, vol. ciii, p. 67, 1904.
[4] Arch. of Physiol., p. 239, 1898.

which a nerve-fiber derives its trophic influence. We should, therefore, find that the axial current in a sensory nerve flows from the ganglion on the posterior root of the spinal nerve toward the periphery in the nerve itself, while in the posterior root the axial current flows toward the spinal column.

The Galvanic Muscular Wave or Porret-Phenomenon.—A muscle undergoes changes in contractibility when dipped into various liquids, such as distilled water, solutions of the alkaline salts, veratrin. This increase in contractibility traverses the muscle in a wave-like manner. It implies an increase in electric excitability, as well as in capacity for contraction. Kuhne, in 1860, Hermann, in 1898, and E. Meirowsky[1] have studied this experimentally.

The Alkaline Demarcation Current and the Way in which it is Affected by Colloids.—B. Mostinsky[2] has made quantitative researches upon this subject. He placed the gastrocnemius muscle of a frog in contact with solutions of different strengths of chlorid, nitrate or monophosphate of potassium. This was continued until the electric potential of the immersed part remained stationary. The difference in potential between this part and a transverse section of the muscle was measured. There is equality between the two when a 1.3 per cent. solution of chlorid of potassium is used; the electromotive force generated at the line of demarcation between the alkaline solution and the electromotive force called the current of rest are equal. The addition of any colloid substance, such as albumin, for instance, reduced the electromotive force due to contact with the alkaline solution. The colloid substance interferes with the migration of ions from the liquid into the muscle. The unequal migration of positive and negative ions through a semi-permeable membrane is supposed to be the cause of most physiologic electric currents, and ions which do not diffuse through animal membranes should greatly modify physiologic currents.

Currents of Action.—Electric currents are produced during the activity of nerve or muscle or of glandular tissue. Those in the latter develop and disappear less rapidly and may be given the special designation of secretion currents. The epithelium performing the glandular function becomes "negative" to the vascular part of the gland. The part of the muscle or nerve which is in activity is "negative" to other portions of the nerve or muscle. The wave of contraction in muscular tissue or of stimulation in nervous tissue carries with it a state of low electric potential.

The current of action is considered by some authors as identical with nervous activity, and by others as an epiphenomenon not necessarily accompanying this activity. P. Schultz[3] has considered this subject of the occurrence of an electric current corresponding to the current of action, but without the presence of physiologic activity.

The current of action may be passed through a transformer or induction coil, and undergo an increase in voltage so as to produce the physiologic effect of high-tension currents upon other animals. Currents derived from heart or muscle contraction have been transformed in this way by Max Cremer.[4] He has obtained very effective results with

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[1] Archiv. f. die gesam. Physiologie, vol. lxxiii, p. 442, 1899.

[2] Ibid., vol. civ, p. 320, 1904.

[3] Centralblatt f. Physiologie, vol. xviii, p. 619, December 31, 1904.

[4] Zeitsch. f. experiment. Pathol. u. Therapie, vol. xlvii, p. 137, 1905.

a frog's heart. Marey, in 1877, used a transformer in studying the electric shock from the torpedo or electric eel.

The Voltage and Amperage of Bioelectric Currents.—The difference in potential between an active and a passive portion of the human body is found by measurement with the potentiometer to be from 0.02 to 0.08 volt. This is a very appreciable voltage, but, owing to the very great resistance of the bodily tissues, the current which it produces has very small amperage. Ohms' law is operative here, and as the resistance is hundreds or thousands of ohms, the current strength amounts to between $\frac{1}{10,000}$ and $\frac{1}{1,000,000}$ ampere or $\frac{1}{10}$ and $\frac{1}{1000}$ milliampere in different cases.

In measuring currents of such small magnitude the greatest precautions must be taken not to vitiate the results by the production of electromotive force in applying the measuring apparatus. Two ordinary metallic electrodes applied to the exposed muscle or nerve, themselves excellent electrolytes, form a complete voltaic couple whose electromotive force might be even greater than the physiologic one, and which might also bring about the production of an electromotive force in the tissues acting either with or in opposition to the natural one. In any case it would be difficult to say to what extent the values found were due to natural and to artificial causes connected with the measuring instruments.

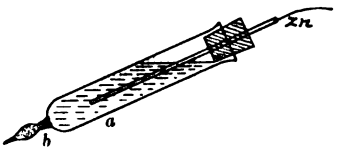

Fig. 190.—DuBois-Reymond impolarizable electrode: *a*, Solution sulphate of zinc; *b*, Potter's clay saturated with salt solution.

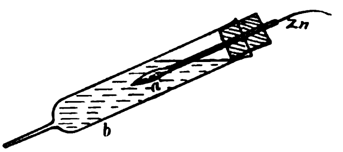

Fig. 191.—D'Arsonval's electrode: *a*, Silver on which is fused chlorid of silver; *b*, solution chlorid of sodium.

Impolarizable Electrodes.—Electrodes which are as free as possible from any such disturbing effect are those suggested by Reynault and DuBois-Reymond (Fig. 190). Both electrodes are just alike, and each consists of an amalgamated zinc rod to which the conducting wire is attached, and which dips into a tube filled with concentrated solution of zinc sulphate, $Zn\ SO_4$, the tube being closed at the bottom by clay moistened with salt solution, $Na\ Cl$. The clay is shaped like a pencil, and is the part of the electrode that is applied to the tissues.

The d'Arsonval impolarizable electrode is not completely so, but is only approximately so, and will do for the less delicate experiments. It consists (Fig. 191) of a tube drawn out into a fine open point and filled with a solution of chlorid of sodium, 7 : 1000, in which is immersed a silver wire upon which chlorid of silver has been fused.

D'Arsonval electrodes, silver covered by a layer of chlorid of silver, are not entirely non-polarizable. These electrodes dipped in a 0.6 per cent. solution of sodium chlorid with a constant current show a current of polarization after the primary current is turned off, amounting to 8 per cent. of the latter (von Pirquet). And Homburger's observations go to show that they present great resistance to the flow of the current. Chlorid of silver is a non-conductor at ordinary temperatures, and the current is from the silver itself through fissures in the chlorid of silver.

A similar type of impolarizable electrode consists of a jar containing a saturated solution of sulphate of zinc into which a zinc wire leads, and from which a piece of filter-paper saturated with a $\frac{7}{1000}$ solution of chlorid of sodium leads to the tissue to be tested. The electrode from the other terminal of the galvanometer is of exactly similar construction. This type of non-polarizable electrode is not available when it is desired to apply the electrometric measurement to a very small surface.

Electrodes of mercury and a solution of chlorid of potassium are only feebly polarizable, and so are electrodes of cadmium in a decinormal solution of chlorid of sodium. Electrodes made of gold and cadmium coupled together, or of gold and silver, or of gold and copper, or of aluminum, or of aluminum and cadmium, are feebly polarizable. The oxidizable electrodes of silver, nickel, copper, tin, or mercury are not free from polarization. W. Cowl[1] has made a thorough study of this subject, with the result in favor of DuBois-Reymond's electrodes of amalgamated zinc in a neutral saturated solution of sulphate of zinc.

Muscles and nerves are themselves polarized to a slight extent, even by very weak currents, without regard to the nature of the electrode. Currents as weak as 0.0044 milliampere will produce this effect. The most delicate galvanometers are required for the measurement of these currents. The Thomson astatic needle or the d'Arsonval movable coil galvanometer, if made with a great many turns of fine wire, is suitable for measuring the current. The capillary electrometer is the best instrument for use in the potentiometer in measuring the voltage.

The mercury and calomel normal electrode can be used in the way explained on p. 165, as an absolute measure of the potential of a single electrode applied to any part of the bodily tissues. The difference in potential between any two portions can be readily calculated from their absolute potentials.

The current of action is always present when a muscle contracts or a nerve transmits an impulse. This occurs whether the function is performed in consequence of natural or artificial causes. And there is no current of action without the performance of function; and no performance of function without a corresponding current of action. The current of action is found in the muscle when the latter contracts in pinching or pricking its motor nerve.

Wave of Negative Variation.—The current of action or, to be more exact, the wave of low potential travels faster in the higher animal or organ than in those of lower development. Its duration is short if its propagation is rapid. The rate of the latter is sometimes 30 meters a second. A galvanometer may be connected by DuBois-Reymond electrodes with two portions of the length of a nerve which is uninjured, and consequently presents no current of rest. Then if an irritation is applied to some other part of the length of the nerve, the galvanometer will probably fail to show any current. This is due to the fact that when the wave of low potential reaches the point nearest the place of irritation, the point reached becomes negative to the other more distant point. At a later period the wave of low potential reaches the more distant point, and conditions are reversed. A current will accordingly pass through the galvanometer at first in one direction and then in the other, and the alternation is accomplished in such a short space of time

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[1] Archiv. f. Physiologie, 1899, 326.

that the ordinary galvanometer will indicate neither current. A photographic chart of the capillary electrometer will show these two currents succeeding each other and in opposite directions, and so will Einthoven's string galvanometer, which reacts with extreme rapidity. During a tetanic contraction of a muscle caused by a rapid succession of stimuli, such as the faradic current (applied at a point not included between the two electrodes from the galvanometer), the circuit formed by the galvanometer and the included portion of muscle will be the seat of a monophase alternating current. Under these circumstances the galvanometer sometimes shows a deflection indicating that the wave of low potential is stronger at the point nearest the source of irritation, and loses some of its strength before reaching the more distant point. The current will be stronger in one direction at the first period than it is in the opposite direction at the second period. The name *decremential current* has been given to this preponderance of current in one direction which is sometimes demonstrable.

There is a chronologic correspondence between the myographic curve indicating shortening or lateral swelling of a muscle stimulated by electricity and the electrometric curve indicating the wave of negative variation.[1] And this is true of both isotonic and isometric contraction.

The most satisfactory observations upon the rate of transmission of the "negative" wave or wave of low potential have been made upon living muscle and nerve preparations with parallel transverse sections. These tissues have a current of rest which is fairly uniform and is caused by the low potential at the transversely cut ends of the muscular cylinder or of the nerve. A potentiometer with one DuBois-Reymond electrode applied at a point on the longitudinal surface of the muscle and another at the transversely cut surface will show a constant difference in potential, which, however, is much reduced when the wave of low potential reaches the longitudinal point. The potential at the latter point will not fall below that of the transversely cut end, but it is reduced to an extent and in a way which can be accurately determined.

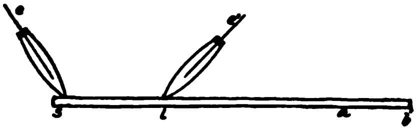

Fig. 192.—Testing a nerve for negative variation. Two impolarizable electrodes applied.

Apply impolarizable electrodes at *S* near cut surface and *L* on lateral surface of the nerve shown in Fig. 192. Then a current flows through the galvanometer from *L* to *S* which is negative.

Now apply a tetanizing current at *a–b*. All parts of the nerve are affected as if injured and the point *L* becomes negative in comparison with what it was before. There is less difference between *L* and *S* and the current of rest is diminished. The wave of low potential (Fig. 193) produces a very sharp fall in potential, followed by a more gradual rise to the original level. It starts from the place of irritation at the moment that the latter is applied, without any latent period, and reaches different points in periods of time proportional to their distance from the point of irritation. It travels in muscle at the same rate as the wave of contraction, but very slightly in advance. It does not necessarily reach its maximum electrically before the muscular contraction begins.

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[1] Paul Jensen, Arch. f. d. ges. Physiol., lxxvii, 107, 1899.

The rapidity of the forward progress and of the fall and rise of the wave of low potential varies in different tissues. Boruttau gives the following as the order in which they increase in rapidity; medullated nerve-fibers, striped muscle, non-medullated nerve, cardiac muscle, unstriped muscle. The fastest rate is about 30 meters a second.

The duration of the negative wave at any point varies inversely with the rapidity of progress of the wave, and with the abruptness of its rise and fall. Examples given by Boruttau of duration of the low potential are: (1) In the striped muscular fiber of the sartorius in a frog, 0.06 second or more, and of this, 0.005 second elapses between the commencement and the maximum of the wave; the subsidence takes ten times as long. (2) In the sciatic nerve of a frog the wave takes 0.006 or more second to pass a given point and 0.001 to reach its maximum.

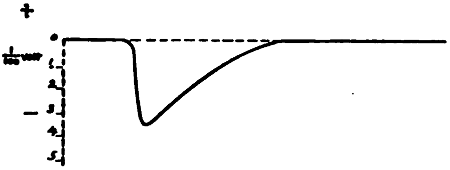

Fig. 193.—The wave of negative variation or low potential.

The words irritation, stimulation, and stimulus are used synonymously in these paragraphs.

An alternating current passes through an external conductor whose two electrodes are applied at points along the course of a nerve or muscle at different distances from the point of irritation. In the case of a single application of the irritation the electric potential at the nearer point as compared with that at the farther point will show changes corresponding with the wave of low potential, providing that the two points are far enough apart for the wave to completely pass the first before any part of it reaches the second point and providing the wave loses but little force (in the shape of decremential current). The graphic chart of the potentiometer would give the potential at the first point, relative to that at the farther point, shown in Fig. 194. Before the arrival of the wave of low potential the relative potential is zero; with the arrival of the wave it falls by a sharp incline a few hundredths of a volt and then by a much longer incline rises to the zero level where it remains until it shows an abrupt rise of a few hundredths of a volt and a gradual fall to the zero level. This curve of relative high tension at the nearer point indicates the presence of the wave of low potential at the further

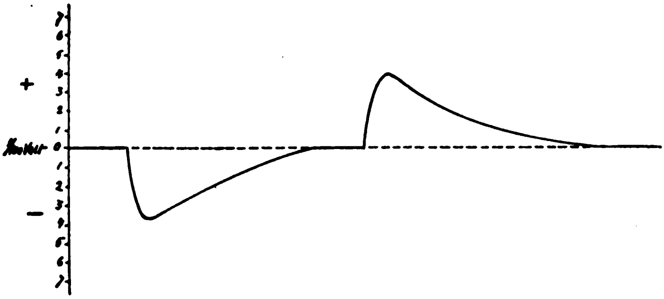

Fig. 194.—Alternating relative potential produced as the wave of negative variation advances.

point. The only change occurring in the absolute potential of the nearer point is at the time that it shows a wave-like fall, followed by a rise to the zero level. From this time on the absolute potential at the first point is unchanged, but it shows a wave of *relatively* high potential, indicative of the arrival of the area of low potential at the further point.

The Electric Variations in the Human Heart.—These may be registered by a capillary electrometer connected with non-polarizable electrodes placed upon the surface of the body near the base and near the apex of the heart.

Another Example of Negative Variation in a Nerve.—Impolarizable electrodes are applied to the lateral surface and the cut end of a nerve. The latter, being injured tissue, is negative to the former, and a current flows through the galvanometer from the lateral surface to the cut end. A faradic current may now be applied to the nerve by two electrodes placed close together at points at some distance, and both in the same direction, from the part to be tested. This stimulation causes each successive part of the nerve to behave as if injured. The galvanometer shows a weaker current from the lateral surface to the cut extremity of the nerve, and this indicates that the lateral surface has changed toward a negative electric potential.

It is very easy to observe the negative variation caused by a continuous current flowing for a considerable length of time, and it is also possible by delicate apparatus to show the negative variation due to a current lasting no longer than an electric spark. Such observations as the latter show that the negative variation occurs a certain length of time after the application of the stimulus, and that the retardation is in proportion to the length of nerve to be traversed. The negative variation or condition of negative electric charge advances in a wave-like manner from the point of application. The rate of propagation of the wave of negative variation is found to be the same as that of the transmission of the nervous impulse.

Negative Variation in Muscle.—This may be produced in the same way as in a nerve, and is similar in character.

Masking of the Wave of Low Potential by Superposition (Hermann).—This does not occur when only the absolute potential at a single point is observed. There the wave is seen to pass as a single sharp depression from the original level, and a more gradual return to it. There is no movement in the opposite, positive direction. The original level has an absolute potential which may be zero, or somewhat above or below that figure. Neither is the wave of low potential masked by superposition when the relative potential is observed between two points the distance between which is greater than the total length of the wave. In this case the absolute potential at the nearer point returns to the original level of equal potential before the wave of low potential reaches the further point. During the entire passage of the wave of low potential at the first point there is no change from the original level at the second point, and the change in relative potential is due simply to the passage of the wave at the first point. Similarly, the passage of the wave at the second point is the only factor in determining the relative potential at this time, for the absolute potential at the first point has before this returned to the original level of equal potential, and remains there. This condition is shown in Fig. 194, where the original equal potential is marked O, not because the absolute potential is necessarily zero, but because the chart is one of the relative potential of the nearer point as compared with the potential at the further point. The level marked O is the level at which there is no difference in potential between the two points.

The case in which superposition masks the wave of low potential is that in which the electrodes of the potentiometer are applied at points so near together that the beginning of the wave of low potential reaches the further point before the wave has completely passed the nearer point. The relative potential at the first point is determined partly by the change in absolute potential occurring there as the wave of low potential passes, and also by the change in absolute potential at the further point. Fig. 195 shows the curve of relative potential, the heavy line being the actual curve. The dotted line shows the curve which would be formed under the influence of the wave of low potential at the first point alone. The interrupted line shows the curve of relative potential which would occur under the influence of the wave of low potential at the further point alone. At the beginning the wave of low potential is not masked, and the curve is due simply to the wave of low potential at the nearer point. But at a later period of time, represented by progress toward the right in the diagram, the curve is modified by the fact that the wave of low potential has reached the further point. At any given time after this the actual relative potential at the nearer point is intermediate between the relatively low potential due to the wave of low potential at this point and the relatively high potential at this point due to the wave of low potential at the further point. The result, as shown in the diagram, is that a potentiometer whose specially prepared electrodes are at two points of the longitudinal surface of the nerve will show the wave of low potential as a sharp fall in relative potential at the nearer point, with an equally sharp recovery, but with only a slight deviation in the opposite direction, of relatively high potential. The second phase is still further reduced if there is a material loss in power, as the wave of low potential progresses along the nerve (decremential current). Accordingly, an exceedingly sensitive galvanometer,—4000 to 24,000 turns of very fine wire,—connected with two points of the length of a nerve nearer together than the length of the wave of low potential, would show the presence of a decided current in a direction from the further to the nearer point in the external circuit, followed by a much weaker current in the opposite direction. The direction of the stronger current in the nerve is away from the source of irritation and of the weaker current toward the point of irritation. Fig. 196 shows the direction of the current during the first phase of the

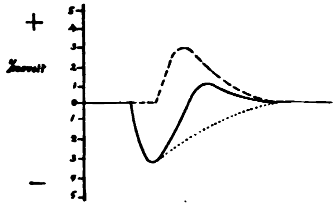

Fig. 195 —Masking of the wave of negative variation by superposition.

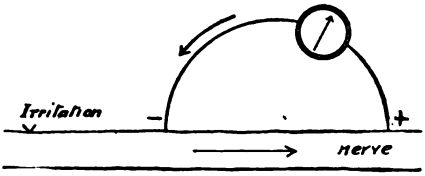

Fig. 196.—Current during the first phase of the wave of low potential.

wave of low potential when the potential at the point nearer the source of irritation has a lower potential than the further point. During the weaker second phase, described in the paragraphs immediately preceding, the + and − sign and the arrows indicating the direction of the current would be reversed.

Superposition of the negative wave or of the wave of low potential would produce a practically undirectional interrupted current through a nerve or muscle if a series of stimuli, such as the faradic current, were applied at intervals so short that the successive waves of low potential trod upon each other's heels.

Fatigue, narcosis, and degeneration make the recovery in potential much less abrupt by retarding the return of the tissues to a normal condition after the passage of the influence which has caused the fall in potential. The curve representing the passage of a wave of low potential consequent upon a single irritation would, accordingly, show the usual abrupt fall, but a much more gradual rise to the original level. When the influences referred to were very marked, the fall in potential would also be retarded.

Effect of Narcotics upon Negative Variation in the Nerve.—A nerve which is exposed to the vapor of ether or of chloroform does not exhibit a negative variation when stimulated, but it will do so after the narcotic is withdrawn unless it has been applied too strongly or for too long a time.

Carbonic acid increases the negative variation in small doses, but it acts like chloroform or ether when applied in large doses.

Absence of Effect of Fatigue upon Negative Variation in the Nerve.—Stimulation of the nerve at regular intervals—every minute, for example—results in an equal negative variation, as shown by the electrometer, but the resulting muscular contraction becomes progressively less. The negative variation in the nerve is closely associated with the transmission of the nervous impulse. The fact that no diminution takes place in the negative variation of the nerve leads to the conclusion that the nerve does not undergo a change in transmissibility in consequence of fatigue. The lessened muscular contraction is due, therefore, to fatigue of the muscle itself.

Cold retards every portion of the wave and draws out the graphic curve in a horizontal direction, while warmth has a contrary effect. According to Boruttau, both these influence only the portion of the nerve or muscle to which they are applied, not the other portions of its length.

These electric currents and others to be described arise in the various tissues in the ordinary performance of the voluntary and involuntary functions of animal and vegetable life. It is only in certain exceptional cases, however, that the potentials generated are so high as to produce effects perceptible without the aid of apparatus. The various electric fish and eels do, however, produce electric discharges violent enough to serve as means of offense or defense, and to produce a benumbing effect upon other living creatures. An electromotive force of 100 volts may be generated apparently at will in the electric organs of these fish. These organs resemble histologically modified muscles in which the fibers are arranged transversely instead of longitudinally, and in which each fiber is completely covered on one side by a nerve-ending, while the other side has a gelatinous sheath. Each fiber forms a complete little condenser charged at will, and these condensers may be regarded as being set up in multiple series. The voltage is sufficient to produce an electric shock, and the amperage is distinctly appreciable by the galvanometer (electromagnetic effect) or the voltameter (electrolytic effect).

Currents of action occur in plants, especially in the sensitive plant and others which respond visibly to irritation. They are similar to those in animals, but the wave of low potential progresses more slowly.

The rate of progress of the wave of low potential, not over 30 meters a second, and often very much less in the case of the current of action in plants or animals, does not indicate the rate of transmission of the same electric current through the tissues. It simply corresponds with the changing position of the active electrode in the natural voltaic couple whose electromotive force causes the current of action. Fig. 197 may serve to elucidate the matter.

The velocity at which the current flows, possibly 180,000 miles a second, will not be materially altered if the pair of electrodes are moved through the electrolyte at the rate of a few yards a second to the positions *w* and *z*.

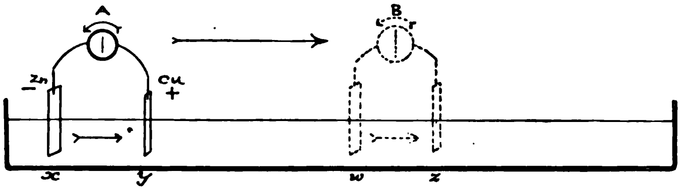

Fig. 197.—A zinc and a copper electrode are immersed at the points *x* and *z* in a long trough of a liquid or gelatinous electrolyte and are connected by an external circuit which includes a galvanometer. Chemic action takes place by which the zinc is attacked and becomes the negative pole of the resulting voltaic cell. The zinc becomes "negative" to the copper in the sense that its potential outside of the liquid is lower than that of the copper, and the current in the external circuit is shown by the galvanometer to pass from the copper to the zinc. Of course, the current is continued through the electrolyte from the zinc to the copper.[1]

The analogy is very close. As in the case of the zinc electrode, the processes taking place at the area of low potential in the nerve or muscle are the cause of the electromotive force. Under the influence of a power inherent in living tissue this area of chemic or physical change advances from one part of the nerve or muscle to another, and so the point of origin of the electromotive force, or the negative wave, passes along the tissue. The position of the copper is of consequence in determining the direction of the current from the zinc electrode through the electrolyte, and by its distance, the amount of resistance. The same remarks are true of the other condition when the wave of low potential is at one electrode.

Local Currents of Action.—The point at which an irritation is applied undergoes a change in potential which is of longer or shorter duration. It becomes "negative" to the unirritated neighboring portions. It is distinct from the progressive negative wave, and is also not to be explained as merely an effect of polarization by the application for an electric current, such as might occur at an electrode in an inorganic electro-

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[1] The established nomenclature by which in such a case the zinc is called the electropositive element and is said to form the negative pole of the voltaic cell necessitates much tedious explanation.

lyte. It follows other stimuli besides electric ones, and is apparently a vital phenomenon. Waller, in 1905, has described blaze currents or alterations in potential at points where the nerve or muscle has been killed by heat.

ELECTROTONUS

This is the name given to the condition of a nerve or muscle beyond and between the two electrodes when a voltaic current is applied to a portion of its length. *Catelectrotonus* occurs in the portion nearest the cathode, and is characterized by the flow of an electric current away from the portion included between the electrodes. Anelectrotonus occurs in the portion nearest the anode, and is characterized by the flow of an electric current toward the portion to which the battery current is applied by the two electrodes. The portion "beyond the anode" has no reference to the idea of distal or proximal as regards the natural relation of the parts in the living animal. It simply means the part of the nerve or muscle nearest the anode, but not included between the cathode and the anode. Reference to Fig. 198, in which the condition of catelectrotonus is indicated at *c* and of anelectrotonus at *a*, will show that the current through the nerve in each case is in the same direction as the battery current through the portion of the nerve between the two electrodes.

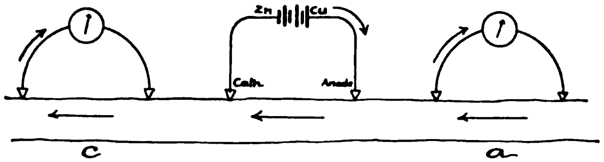

Fig. 198.—Electrotonus: *a*, Anelectrotonus; *c*, catelectrotonus.

Electrotonic Currents.—These are vital phenomena, not merely dependent upon the effect which the battery current would produce in portions of an inorganic conductor outside of the part between the two electrodes. In fact, except between the electrodes the currents are the reverse of those which would be produced by electric diffusion (Fig. 199).

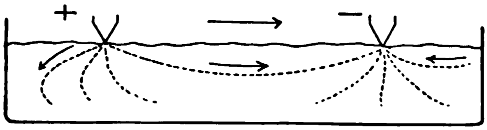

Fig. 199.—Direction of extrapolar currents in case of simple diffusion.

They are continuous currents in the direction shown in Fig. 197, and begin with the application of the battery current and continue to flow as long as it does. They are different from the current of action which if due to the application of a voltaic current would occur only at the beginning and the end of that application. Electrotonic currents occur simultaneously in different parts of the nerve or muscle, and become very much weaker or even entirely disappear at a distance from the portion included between the electrodes. The current of action, on the other hand, progresses in a wave-like manner, so that it occurs first in the portion nearest the point of irritation and later in the portions further away. While the current of action may undergo some loss of power at a distance from the stimulation, it is not anywhere near so great a loss as occurs with electrotonic currents.

The relative strength of anelectrotonus and catelectrotonus varies in different animals, and is influenced by various conditions. Under ordinary circumstances they are about equal in man and other mammals.

Positive After-fluctuation.—After the disappearance of the local current which occurs as an area of low potential at the point of irritation of a nerve or muscle a condition of high potential is sometimes observed there (Hering), and to this the name of positive after-fluctuation has been given. This should be carefully distinguished from the second phase of the negative wave in the current of action where the potential is only relatively high, and which occurs under quite different conditions.

These different currents have been described as a group of currents resulting from vital processes. They are not necessarily physiologic effects of electricity, although the application of the latter is one of the most convenient means of exciting these as well as other vital phenomena experimentally.

Modifications in Electrotonus.—Electrotonic currents do not pass beyond a ligature tied tightly around a nerve.

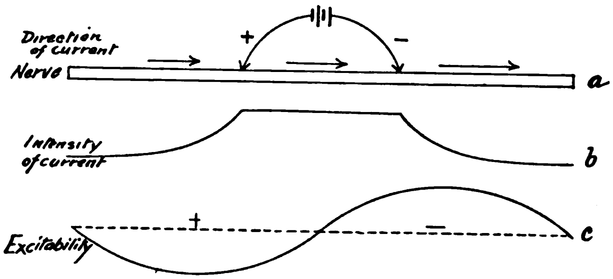

Fig. 200.—Effects of electrotonus at various distances from the electrodes.

Electrotonic phenomena are much diminished by anesthetics.

Electrotonic currents do not immediately disappear when the current is turned off, but persist for a certain length of time with oscillation both in the current strength and in nervous conductibility.

Electrotonic currents increase in intensity with the strength of the exciting current, and diminish very rapidly with the distance from the portion between the electrodes (Fig. 200).

Physiologic Effects of Electrotonus.—The excitability of the nerve is increased in the region of catelectrotonus and diminished in that of anelectrotonus. This is true both beyond and between the electrodes. The diagram in Fig. 200 shows the varied excitability of the nerve—greatest near the cathode and least near the anode.

Excitability is very decidedly affected by electrotonus. Fig. 200, *c*, indicates that at a point midway between the electrodes the excitability is unchanged. Proceeding toward and for a short distance beyond the negative electrode we find that the excitability progressively increases, and then beyond that point it again diminishes to zero. Leaving the central point, we find that the excitability is gradually reduced until after passing the positive electrode, and then gradually becomes zero again.

Electrotonus inhibits nervous conductibility, so that stimulation of a motor nerve at a proximal point will not traverse the portion between the electrodes and cause contraction of the muscle supplied by the nerve. Or, if it does so, it will be with reduced power (Fig. 201).

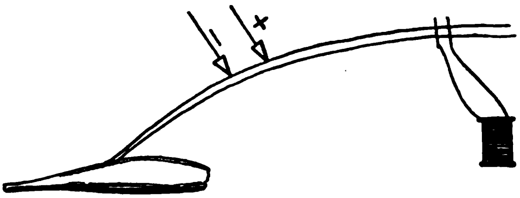

Fig. 201.—Showing the stimulation of a motor nerve by a faradic current; the impulse failing to reach the muscle because the conduction of nerve excitability is blocked by electrotonus produced by a constant current applied between the faradized portion of the nerve and the muscles.

Fig. 202 shows the effect of anelectrotonus in reducing nervous excitability. The nerve in this case is simply exposed, not cut out of the body. The portion in which anelectrotonus is present is that between the galvanic electrodes and the muscle, and to this part an electrode from a faradic coil is applied. The other faradic electrode is applied to some indifferent part of the animal's body. The presence of anelectrotonus reduces the excitability, and makes it necessary to apply a stronger faradic current than usual in order to produce muscular contraction.

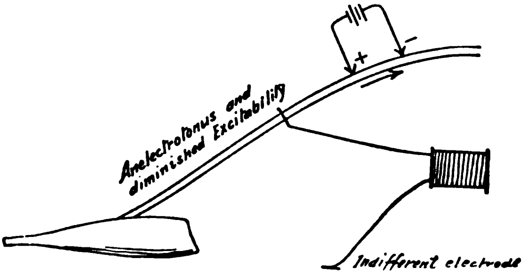

Fig. 202.—Nervous excitability diminished by anelectrotonus.

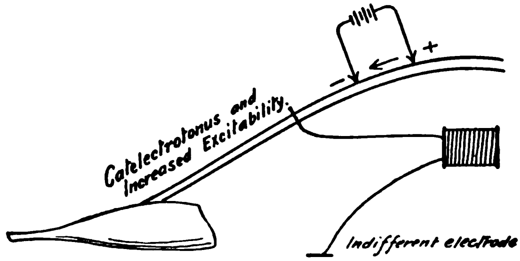

Fig. 203.—Catelectrotonus increases nervous excitability.

Nerve blocking upon this principle is made use of in neuralgia. The anode is applied to the nerve and the current is ascending for sensory and descending for motor nerves.

The increase of excitability produced by catelectrotonus is illustrated by Fig. 203.

Electrotonus Explained on the Theory that the Nerve Acts as a Cored Conductor.—If two electrodes are applied to two points on a simple straight wire, as in Fig. 204, and the current be a continuous one, it will traverse only the portion of the wire between the two electrodes, and in a direction from the positive to the negative electrode. It is different, however, if the wire be immersed in a trough of salt solution, which is a much poorer conductor of electricity than the wire (Fig. 205). A part of the current will pass from one electrode to the other through the liquid alone. Another part of the current traced from the positive electrode will be found to go through the liquid to the nearest part of the wire, and follow this good conducting path toward the other electrode. Other portions of the current radiate from the positive electrode through the liquid in every direction, and reach different points on the wire—some on the portion beyond the positive electrode, others between the two electrodes, but practically none beyond the negative electrode. As we shall see later, the current or the electric pressure in the liquid is in the opposite direction beyond that point. The current flows in the same direction through every portion of the wire. In the portion beyond the positive electrode currents entering the wire at any point find the best conducting path through the wire toward the negative electrode. In the portion between the two electrodes the best conducting path is through the wire toward the negative electrode. But, of course, at every point some current is escaping from the wire to pass through the liquid to the negative electrode. The same escape of the current from the wire through the liquid to the negative electrode takes place at every point beyond the negative electrode, and this enables the current to traverse the wire in the original direction right to the end. The escape of current to or from the wire is greatest at points close to the electrodes where the force of attraction by the opposite polarity is greatest, and it is least at points far away from either electrode, where the attraction is very much weakened by the resistance of the liquid through which the current must pass. Under the conditions of the experiment the only current which can pass through the wire is that which enters and leaves it through the liquid. Consequently, the current through the wire is strongest between the electrodes and near them, and becomes very weak at a distance from them, though it always flows in the same direction. If it proves to be true, it will illustrate in a crude manner that the phenomena of electrotonus may be explained upon the theory that they are due to the nerve acting as a cored conductor (Kernleiter, in German).

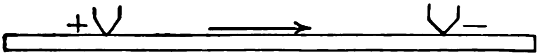

Fig. 204.—Conduction through a simple wire when electrodes are applied laterally.

An experiment has been actually performed by J. Sosnowski[1] with a copper wire embedded in a bar of carbon. The phenomena of elec-

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[1] Centralblatt. f. Physiologie, xix, 33, April 22, 1905.

trotonic currents were duplicated, and his conclusion was that electrotonus is simply a matter of difference in conductivity, and not of polarization or vital processes.

Hermann's theory is that electrotonus is due to polarization between the axis-cylinder and the myelin sheath. The same diagram (Fig. 205) may serve to illustrate this if we suppose the fluid to be a solution of sulphate of zinc, the electrodes to be of zinc, and consequently impolarizable in this liquid, and the wire of platinum. This is an experiment which has actually been tried, with the result that currents are found to flow through all parts of the wire simultaneously and in the same direction. The explanation offered is that there is a polarization of the platinum, which prevents all the current from passing directly to or from the platinum and the nearest electrode; and this causes a diffusion of the current through the liquid to the more distant parts of the wire.

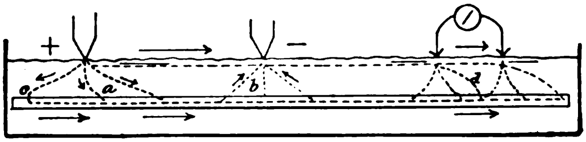

Fig. 205.—Conduction through a cored conductor. Wire in a trough of water.

THE CAUSE OF ANIMAL ELECTRICITY: AN EXAMPLE OF A CONCENTRATION CELL

Two portions of liquid containing an electrolytic salt in different degrees of concentration and separated by a permeable or a "semi-permeable" membrane form a *concentration cell.* The migration of ions through the partition by osmotic pressure gives rise to a difference in potential. If a non-polarizable electrode—one not acted upon by electrolysis—be placed in each portion of fluid, an electric current will pass through an external circuit, connecting the two.

There is no doubt that vital electric currents are produced in this general manner. The ordinary processes account for differences in chemic composition whenever there is a dividing membrane. But the exact mode of development of a difference in potential at a particular time remains the subject of hypothesis in spite of the many important observations by Waller,[1] Boruttau,[2] Tschagowetz,[3] Oker-Blom,[4] MacDonald,[5] Bernstein,[6] and Boruttau,[7] besides the earlier classic observations of DuBois-Reymond, Rutherford, and a host of others.

The following paragraphs are translated from Boruttau, who has studied the subject experimentally and has collated the most recent observations of others:

"All the electric phenomena in living tissues can only be considered

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[1] Croonian Lectures, in Philosophical Transactions of the Royal Society of London, vol. clxxxviii, 1897.

[2] Pflüger's Archiv. für der gesammte Physiologie, vol. lxxxiv, p. 346, 1901.

[3] Considerations Upon Electric Phenomena, etc., St. Petersburg, 1903.

[4] Pflüger's Archiv, vol. lxxxiv, p. 191, 1901.

[5] Proceedings of Royal Society, 1900.

[6] Pflüger's Archiv, vol. xcii, p. 521, 1902.

[7] Die Elektrizitat in der Medizin und Biologie, published in Wiesbaden, 1906.

principally as produced by concentration cells since no metals are present. Their comparative constancy as well as our knowledge of the structure of the tissues make it necessary to assume that the two electrolytes with different degrees of concentration are separated by a 'semipermeable' membrane. This allows one kind of ions to pass through it, but not the other ions, which consequently accumulate upon it (Ostwald, 1890).

"By 'membrane' is generally to be understood the outer and limiting layer of living substance of the simple tissue elements: the ectoplasm, or the cell-membrane, or the sheath structure, such as the sarcolemma, nerve-sheath, etc. A difference in concentration is present upon the two sides of this membrane when electric currents are produced by irritation or natural activity. This may be referred to as increased 'dissimilation' (retrograde tissue change or disintegration) at the point of injury, death of tissue, or irritation. Stimulation is produced in the substance inside of the cell-wall, not in the outer, intercellular fluid. It will be remembered that the irritated place always becomes 'negative' in the same sense as the zinc in a voltaic cell (really electropositive). Consequently, it must be negatively charged ions or anions (ions which travel toward the anode) that are liberated by the increased retrograde tissue changes and press upon the limiting membrane from the inside of the tissue-cell which is impervious to them. The positively charged ions or cations liberated at the same time are free to pass in every direction from the altered place, passing readily through the cell-membrane into the enveloping liquid, described below.

"It must be remembered that free acid results from the death or activity of muscle or other tissue, and Waller and Boruttau have called attention to the fact that various modifications of the current of action in nerves during activity are analogous to those resulting from the action of carbonic acid. Tschagowetz has attempted to calculate the electromotive force from the probable concentration of the carbonic acid in the tissue-cells, and found an electromotive force corresponding quite closely with the observed electromotive force.

"But the process can hardly be as simple as would be represented by the mere statement that $\overset{+}{H}$ cations are freely movable, while the $\overset{-}{CO_3}$ anions cannot pass through the limiting membrane. Living albumin contains, for example, alkaline salts in loose combination, and it seems capable of itself acting as an organic acid. And by its disintegration metallic ions may appear as cations and complicated albuminoid products as anions, which, on account of their complex molecular structure, cannot pass through the 'membrane.' Then, again, a demonstrable acidification does not necessarily indicate an actual excess of $\overset{+}{H}$ ions.

"Waller, in his book 'Kennzeichen des Lebens' ('Characteristic Evidences of Life'), goes somewhat too far in speaking of an (electric) solution pressure (or osmotic pressure) of the protoplasm. This expression has so far been applied only to metallic salts; and, besides, that it would be necessary to limit it to the cations.

"The 'positivity' (or, more properly, 'electronegative behavior') accompanying increased assimilation, as in the positive after-fluctuation and in anelectrotonus, etc., can be explained only on the theory that the local concentration is diminished by the synthetic process, or that the cations which do pass through the 'membrane' are repelled in consequence of the proximity of an anode.

"Oker-Blom and MacDonald, besides Tschagowetz, have sought to find additional evidence in favor of the concentration cell theory as accounting for the demarcation current.[1] They applied different hypotonic and hypertonic solutions to a muscle and to its transversely cut surface, and then tested the difference in potential, using unpolarizable electrodes. Oker-Blom concludes that the concentration cell arises from the alteration in the tissue; while MacDonald and Bernstein conclude that a difference in concentration was previously existent between the protoplasm and the enveloping fluid and when there is an injury, this difference in concentration is conducted at only one place, through the medium of the 'membrane.' Both of these authors prefer the 'membrane' theory to the alteration theory. But this cannot satisfactorily account for the current of action influenced, as it is by narcosis and fatigue.

"The theory of a protoplasmic limiting 'membrane' is of fundamental importance in accounting for local differences in potential, currents from injury, secretion currents, blaze currents, and it is also necessary in the case of every extension and progress of differences in electric potential where the alteration theory alone is insufficient (Boruttau).

"It is necessary to assume the existence, besides the limiting 'membrane,' of an enveloping liquid, which normally is isosmotic with the cell contents. There are also fibrillary structures which conduct stimuli, muscle fibrilla in the sarcoplasma, neurofibrilla in the axis-cylinder liquid, etc. There are, consequently, structures which possess a certain analogy to the polarized nuclear conducting models which were formerly so much used, as in demonstrations of the electrotonic currents in nerves, etc. The resemblance is to the extent that the local equalization of concentration difference and of potential difference (local current) causes the same thing to take place in the adjacent tissue, etc. In other words, this theory of nuclear conducting fibrilla and a limiting membrane with an enveloping liquid explains the wave-like progress of the current of action with the concurrent wave of contraction, and probably a wave-like progress of tissue changes. The limiting membrane theory (concentration cell theory, S. T.) furnishes the key to the understanding of the conduction of stimuli upon electrochemic principles.

"Not much can be said here about the mathematic calculations, which at present concern only polarized nuclear conductors of Hermann, Hoorweg, and Cremer, but they are still in an incomplete state.

"The origin of the extrapolar electrotonic currents is directly dependent upon the attraction or repulsion of the ions of the enveloping liquid by the battery electrodes and the semipermeable character of the limiting membrane. The more resistant is the membrane, the stronger the current; it is greatest in medullated nerves, and least in muscular fibers."

Significance of the "Alteration Negativity."—"Regions of tissue changes immediately become 'negative' in consequence of the

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[1] This has reference to the current of rest which occurs between dying tissue and tissue on the other side of the line of demarcation between the living tissue and that which is dying.

greater permeability of the limiting membrane to the cations than to the anionic part of disintegration. This has a close relation to the general laws governing electrical stimulation."

Tchiriev's Results in the Study of Muscular Currents.—A most accurate and complete series of electrometric measurements recorded photographically has been made by S. Tchiriev at Kiev, Russia,[1] and his conclusions are worthy of consideration.

One of his photographic records is reproduced in Fig. 206. Three tracings are shown: *a*, registering the time, each ascent and descent lasting 0.375 second; *b*, the myographic curve; and *c*, the electrometric curve. The gastrocnemius muscle of a frog was not detached and the blood circulation was undisturbed, but the muscle was more or less injured in connecting it with the myograph. Two non-polarizable electrodes connected the muscle with the capillary electrometer which showed a current of rest equal to 0.105 volts.

This was compensated according to duBois-Reymond's method. The sciatic nerve was stimulated *in situ* by isolated induction shocks (currents from an induction coil produced the opening and closing of the primary current) at the rate of 11 opening shocks a second. The myograph indicates an incomplete rhythmic tetanus.

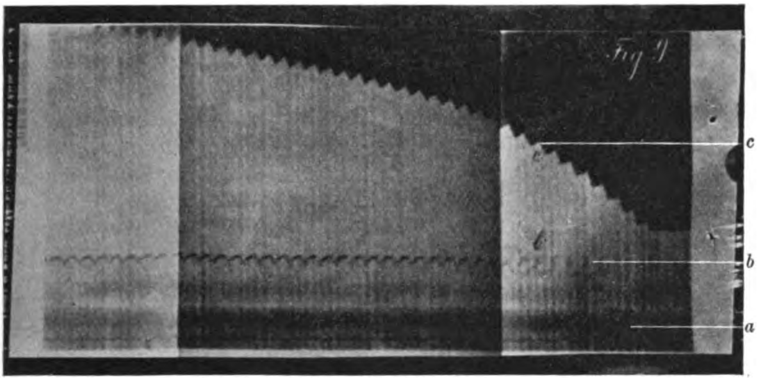

Fig. 206.—Myographic and electrometric curves during stimulation by isolated induction shocks.

The electrometric curve which is the special subject of this study does not show itself like the teeth of a comb as duBois-Reymond supposed. Under the influence of each stimulation a wave of negative electrical potential traverses the muscle and the waves of negative variation succeed each other so rapidly with stimuli applied at the rate mentioned that they overlap. The potential or voltage has not nearly reached the zero point before the next wave arrives. The result is a curve somewhat resembling a flight of stairs. The vertical distances in the chart marked 0, 10, 20, and up to 100 are millivolts.

The electrometric curve is sometimes more like the teeth of a saw. The potential is sometimes reversed so that the curve is below the axis of abscissas instead of above it. These variations occur in different states of the muscle depending upon drying of its surface from exposure to the air and the condition of the circulation in it.

[1] Journal de Physiologie et de Pathologie Generale, vol. vii, p. 593, 1905.

The various photographs corroborate Helmholtz's and Bezold's observation that the negative variation in the muscle begins before the muscular contraction. Each negative wave lasts longer than the muscular contraction which accompanies it, and forms a continuous curve with the succeeding wave.

The myographic curve falls very rapidly after shutting off a current which has caused muscular tetanus, but the electrometric curve may even show an immediate rise, and its fall is always slow and gradual. Tchiriev's conclusion in regard to muscular currents is that negative variation and muscular contraction do not depend upon one another, but upon a common cause—the stimulation of the muscle.

Tchiriev's Conclusions in Regard to Bio-electric Currents.—1. The living and perfectly intact tissues and organs, for example, nerve, brain, and heart, do not show even slight currents or difference in potential, which could possibly be considered as playing a rôle in the performance of their functions or in the activities of the general system.

2. The same tissues show a difference in potential when they are injured. The injured part is negative to the uninjured part. The transversely cut surface of a muscle or a nerve is negative to the longitudinal surface of the fibers.

3. The sources of this electromotive force are preëxistent in the tissues. This is shown by (*a*) The difference in potential when injured: (*b*) the various phenomena of electrotonus; (*c*) the electric organs of certain fishes.

4. Stimulation of intact tissues, such as nerves and muscles, produces physiologic effects, but not a trace of change in electric potential.

5. If the muscle or nerve has been injured and hence gives an electric current of its own, stimulation will then produce an electric effect in addition to the physiologic effect of contraction or other activity. The electric effect is purely a physical one, a negative variation, and the stronger the muscular current proper, and the fresher and more vital the tissues, the stronger is this negative variation resulting from stimulation.

6. The mode of production of this negative variation seems to be that the denuded sources of electromotive force undergo a change in position which makes them act more feebly. This depends upon a physical mobility, and consequently muscle, on account of rigor mortis, soon ceases to show a negative variation when stimulated; but nerve retains this property for a long time.

7. Physiologic function and negative variation are independent of each other as to time and amount.

8. Stimulation is transmitted along intact nerve-fibers independently of any sort of variation in electric potential. There is no electric variation to be found in testing the surface of the intact brain when the organs of sense are stimulated.

9. Rhythmic stimulation of the nerve supplying an uninjured muscle not detached from the body, and with its circulation unimpaired, produces contraction, but no electric currents. There may be separate contractions or tetanus. There is either no electric change or insignificant oscillations of less than 0.001 millivolt.

10. Muscular contraction may be produced through the intermediary of the spinal cord, or by chemic stimulation of the nerve, or by electrolysis, as observed after the rupture of a constant current which has

been flowing for a long time. The result in any of these cases is a tetanic contraction of longer or shorter duration.

The *electrocardiogram* is a graphic tracing of the electric currents produced by the contraction of the heart muscles; has become an important factor in cardiovascular diagnosis. (See page 321.)

11. Spontaneous tetanus and tetanus as seen in voluntary muscular contraction is a complete non-rhythmic continuous contraction. Rhythmic tetanus is produced only by rhythmic stimulation of the nerve or muscle.

12. An injured muscle giving a current of rest may be caused by rhythmic stimulation to exhibit marked steps or dentitions in the electrometric curve of the negative variation. This may produce tetanic contraction in muscles of the other leg whose nerve has been placed along this muscle, just as if the stimulated muscle yielded a faradic current.

13. Injured tissues and organs, especially muscles and nerves, show certain electromotive changes when performing physiologic functions, but it does not follow that these electric properties which are inherent in the tissues take any more direct part in physiologic activity than the other physical and chemic properties of the tissues.

14. Electrotonus of a nerve is not a process of polarization in the ordinary sense in which that takes place in inorganic substances, but is due to a displacement of the sources of electromotive force in the nerve itself under the influence of the constant current.

These are the deliberately formed opinions of a man who has made wonderfully careful measurements of the actual electric conditions accompanying physiologic activity. He does not think that under normal conditions there are electric currents of sufficient intensity to be the causative factor in physiologic activity. He thinks that the infinitesimal currents which are normally present are only a part of the general chemic and physical changes occurring in living tissues, and are not the sole and regulating causes of activity. According to his view, physiologic currents of electricity are phenomena, not causative factors of muscular contraction and of transmission of nervous stimulation.

If these views are correct, it would still remain true that electricity artificially applied is one of the most effective means of exciting physiologic activity.

PHYSIOLOGIC EFFECTS OF ELECTRICITY

PHYSIOLOGIC EFFECTS OF ELECTRICITY UPON MICROÖRGANISMS

Galvanotaxis occurs when a current of electricity passes through a medium, usually liquid, in which small living organisms tend to move toward one or other electrode under the influence of the current.

The tendency of a living organism to arrange itself so that its long axis shall bear a certain relation, either parallel or at a right angle to the direction of the current, is called *galvanotaxis*. It is analogous to the way in which a shoal of small fishes will all head the same way, swimming against the current which is carrying them along in a brook.

These properties are exhibited by living organisms of different sizes, even by those which consist of only a single cell. Protozoa, infusoria, fish, and tadpoles have been used in many experiments.

Galvanotaxis seems to permit of a purely physicochemic explanation as not necessarily a vital phenomenon. A cell may acquire an electric charge from the unequal penetration of ions of different sizes (positive or negative) through its enveloping membrane. This depends upon the semipermeable character of the membrane, and the osmotic pressure and degree of concentration of the positive or negative ions inside the cell, and in the electrolytic solution in which it lies. A cell which has thus acquired a positive electric charge will be attracted toward the negative electrode, and one with a negative charge will tend to move toward the positive electrode. A. Coehm and W. Barrott[1] have studied the phenomena of galvanotaxis from this point of view. Paramecia, large ciliated infusoria, swim toward the cathode when in a dilute solution of sodium chlorid. But it is not so simple a matter with fish and other highly organized animals, where the central nervous system and other complex organs must be called into play.

Galvanotropism is still more complicated, and seems decidedly the effect of stimulation of living tissues and not a mere physical effect upon a certain mass of matter. It is the growth or bending of a living organism into a certain relation with a galvanic current. It may be likened to the growth of a house-plant toward a lighted window. The early observations of Verworn and Lidloff have been supplemented by the studies of Henri Mouton,[2] distinguishing between galvanotropism and the chemiotropic effect produced upon infusoria from chemic changes in the neighborhood of the electrodes.

The still more recent observations of P. Statkewitsch[3] show the effect of different electric applications. Periodically alternating currents with a slow rhythm cause paramecia to undergo a balancing movement through a half-circle, so as to present their anterior extremity toward the cathode each time. But with a more rapid alternation of the current there is transverse galvanotropism and galvanotaxis. These phenomena take place first in the central part of the preparation, when

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[1] Zeitschrift für allg. Physiol., vol. v, p. 1, 1905.

[2] C. R. Acad. des Sci., 127, 1247, May 15, 1899.

[3] Journal de Physiologie et de Pathologie Generale, 1905.

the current is of medium strength and medium frequency of alternation. Some organisms, like Stylonychia mytilus, show transverse galvanotropism with quite slow alternations of the current, and in this particular case the peristome is directed toward the cathode. Any given species of protozoa presents different stages and types of galvanotropism and galvanotaxis with different intensities of the current. According to Statkewitsch's observations, protozoa which are fixed upon or near little solid masses exhibit much slower and less energetic galvanotropism and galvanotaxis because of the effect this obstacle has upon the current. He believes that galvanotropism is an active process, not to be explained by cataphoresis or any purely physical theory. It is noteworthy, however, that inorganic particles may exhibit motion under the influence of the same current, and this is sometimes in the opposite direction from that taken by protozoa.

Microörganisms undergo changes in shape and consistence under the influence of an electric current passing through the medium in which they lie. The ameba puts out projections from the cell-body, pseudopodia, toward the anode, and undergoes granular degeneration when too strong a current is applied.

It appears to the author that these different phenomena have partly a physical and partly a physiologic basis; that there are the direct effects of ionization, secondary chemic changes, cataphoresis, and heat upon the substance of the organisms, as well as the indirect effects excited in the organism by these actions of the electric current.

Schatzki[1] has experimented with a variety of pathogenic microorganisms, especially noting the effect at a distance from both poles. He found that galvanic currents of from 20 to 30 milliamperes, applied for from one and one-half to two hours, completely abolished the virulence of these microbes; succeeding generations from microbes thus galvanized possessed less vitality as to virulence, as to activity, and as to growth. The medium through which the current was passed was contained in a glass tube 1 cm. in diameter and 20 cm. long.

PHYSIOLOGIC EFFECTS UPON VERTEBRATE ANIMALS

The most important part of the effect of low-tension currents—up to 110 volts—is upon the heart. There is a fibrillary tremor, an irregular fluttering of the ventricles, while the auricles continue to beat regularly. This has been studied by applying induced currents to the exposed heart of different animals. The exposed heart of a dog never regains its rhythmic beat after fibrillary tremor has been caused by induced currents. The exposed heart in an adult guinea-pig can be revived with difficulty by cardiac massage and artificial respiration. A rabbit's heart usually revives spontaneously. The rat's heart revives as soon as the current is turned off.

There is the same effect upon the heart when low-tension alternating currents are applied to the unoperated animal through mouth and rectal electrodes.

The electric resistance in a dog weighing twelve to twenty-four pounds is from 250 to 350 ohms, and an alternating current of *five volts for ten seconds* sometimes causes a cry of pain, or sometimes nothing beyond a slight rise in blood-pressure.

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[1] Bulletin officiel de la Société française d'Electrothérapie, December, 1907.

Ten volts for ten seconds sometimes interrupts the cardiac rhythm and sometimes causes fibrillary tremor of the heart and death.

Ten volts for two seconds, with the pneumogastric nerve severed, causes death by fibrillary tremor of the heart.

Respiration is interfered with in all the above cases by a general condition of muscular contraction,—tetanus,—but becomes reëstablished as soon as the current is turned off. Respiration gradually fails when the heart is permanently paralyzed.

An alternating current of from 20 to 40 volts produces the same fatal effect, and requires only a second or two of contact. Convulsions are added, and the animal is in opisthotonos or generalized tetanus lasting five seconds after the current is turned off, and followed by clonic convulsions which gradually cease. Respiration which has been embarrassed by the tetanic contraction recovers and continues for quite a long time. Sensation is not much affected. The corneal reflex is preserved. Death results from almost instant cardiac paralysis, but the other functions of the living organism continue for a time and gradually die out as a secondary consequence of the failure of the circulation.

An alternating current of from 80 to 120 volts applied by electrodes placed upon the shaven head and the shaven left thigh for at least one second produce the same results as have just been described for currents of 20 to 40 volts. The resistance in the case of electrodes upon the head and thigh is 400 ohms.

The paralysis of the heart occurs at once in all these cases, but the blood-pressure shows an initial elevation, followed by a gradual decline. Prévost and Battelli attribute this to vasomotor stimulation in both arteries and veins, slowing the passage of blood through the arteries from the heart, and pressing it through the veins toward the heart.

The thorax being opened, the ventricles are seen in some cases to be in a state of fibrillary tremor, while the auricles beat regularly for perhaps as long as fifteen minutes.

Artificial respiration alone does not do any good, but cardiac massage and artificial respiration combined keep the animal alive as long as they are continued. During this period sensibility is normal.

A current applied by electrodes placed upon the two sides of the thorax encountered a resistance of 280 to 320 ohms. Ten volts applied for five seconds killed one dog, while two others survived. One of the latter was killed by a current of 15 volts applied for five seconds.

Similar results attended the application of the electrodes to both forelegs.

Summary of the Effects of Low-tension Alternating Currents up to 120 Volts.—There are slight *nervous disturbances* in dogs, guinea-pigs, rabbits, rats, etc. Respiration is only temporarily arrested, and general sensibility is but little affected. Twenty volts will produce *general tetanus* with opisthotonos if one of the electrodes is applied to the animal's head, but at least 60 volts are required when both electrodes are applied to the forelimbs. The effect upon the *heart* is to produce fibrillary tremor, which, as previously explained, is fatal in some animals and may be recovered from in others. *Respiration* is not primarily affected. It is not paralyzed in dogs or guinea-pigs, and in them artificial respiration does no good.

A current of 20 or even of 10 volts applied for one second will produce fibrillary tremor of the heart if this organ lies in the direct path between the electrodes. This is the case when one electrode is applied to the animal's head and the other to the thigh, or when one is placed over the cardiac region.

Preliminary section of the pneumogastric nerve has no effect upon the production of fibrillary tremor.

Battelli considers it probable that fatal effects from low-tension currents in man are produced in the way detailed above, viz., by primary cardiac paralysis.

The Effect of High-tension Currents.—A current of 220 volts in the case of the rabbit, or 550 volts in dogs, does not produce fibrillary tremor of the heart or death by primary cardiac paralysis. There is only a temporary arrest of the auricles from stimulation of the pneumogastric nerve. Respiration, on the contrary, is impaired by an effect upon the respiratory center in the medulla. This effect may vary in degree. Respiration may be spontaneously renewed after the current has ceased, or, if it does not return of itself, it may be readily brought about by artificial respiration.

Shocks from currents of this voltage are not ordinarily fatal if the proper treatment, artificial respiration, is applied.

The Effect of Very High-tension Currents.—Currents of from 1000 to 10,000 volts, as employed in the long-distance transmission of power, produce mechanic lesions of the tissues traversed, just as lightning does. Fatal hemorrhages in the substance of the central nervous system may cause irreparable paralysis of respiration and other functions (Jellinek). These very high-tension currents are often instantly fatal, but the effect varies greatly with the path traversed by the current in passing through the body. If the heart and the central nervous system are not in the direct path of the current, they may receive only a fraction of the original current, and the effect may correspond to that of a medium or low voltage. The reverse is true as to low-tension currents applied directly to vital organs.

From 90 to 115 volts have killed men by cardiac paralysis under exceptional conditions as to electric conduction. On the other hand, in a case which came to my own knowledge, a shock from a 2200-volt alternating current was survived, with no permanent damage except a deeply grooved scar of the hand and a fairly well-united fracture of the femur.

Legal electrocution by means of an alternating current of from 1300 to 1700 volts is not always immediately fatal, because it aims to produce respiratory paralysis, and it sometimes requires three or four applications to make this paralysis permanent.

Prévost's animal experiments show that a heart in which fibrillary tremor has been induced by a current of 50 volts may sometimes be reanimated by a current of 4800 volts applied ten seconds later. This is not to be recommended in the treatment of human beings shocked by electricity.

The Relation of Amperage and Voltage to the Physiologic Effect.—Industrial currents for light and power, if alternating, usually have about 50 periods a second, and this rate is very active physiologically. These currents have such tremendous volume that contact with a conductor carrying a current of 10,000 volts must be absolutely guarded against. No person must be allowed to approach within sparking distance of such a conductor, and no other conductor must be allowed to touch it or come near it. The *crossing* of a high-tension conductor by a wire which is supposed to carry a perfectly harmless current is a frequent cause of fatal accidents. These industrial currents are capable of sending a fatal number of amperes or too large a quantity of electricity through the resistance offered by the animal body.

Harmlessness of High-tension Therapeutic Applications.—The reason for this is that the static electric machine, for instance, produces so very small a quantity of electricity that although its tension is sufficiently high to send it all through the body, it still produces no harmful effect.

Then, again, the very rapidly oscillating high-tension Tesla currents do no harm because the transmission of ions through the semipermeable membrane of the electrically conducting human body cannot keep up such rapid rhythm, and so only a part of the potential variations affects the body (Boruttau).

THE EFFECT OF ELECTRICITY UPON ANIMAL TISSUES

The effects vary with the voltage and amperage of the current applied, and also with its density and direction. They are very largely due to electrolysis, and, as in the case of an ordinary electrolytic cell, are chiefly evident at the points of contact with the electrodes. This is all the more certain to be the case because of the wide diffusion of the current in the tissues between the two electrodes. Sometimes the mechanically rending effect of an electric discharge is produced in the tissues, but this must be quite exceptional. Lightning splits a great tree from top to bottom by an explosive effect due to the heating of air and watery vapor and the gaseous products of electrolysis in the cellular structure of the wood. Such an effect is not produced upon men or animals even by a lightning stroke. The human body is quite a good conductor of electricity as compared with the insulating properties of dry wood. And the current can pass through any part of the body or along its surface with about equal readiness, whereas in a tree there may be one or more long tracts filled with readily conducting moisture surrounded by quite dry and consequently non-conducting fibers. In the latter case we have the familiar generation of intense heat produced by a current forced by its high voltage through a conductor too small to carry it. This is not the case with the human body, since it has a sufficient carrying capacity for the heaviest artificial or natural currents.

The minute hemorrhages found in the nervous centers in some cases of death by high-tension currents can hardly be considered in the same category with the effect which the same lightning bolt may produce in splitting a giant oak which twenty men could not have torn asunder.

The heating effect upon the tissues due to ohmic or frictional resistance must be very slight indeed in all cases where a surface electrode is used, and also in cases of lightning stroke and injury from accidental contact with conductors of high-tension electricity. The burns which do occur in these cases and in electrocution are doubtless due chiefly to electrolytic processes, but it is different when there is only a very small point of contact, like the platinum needle used in electrolysis. There, if the current is of considerable strength, we should have a direct heating effect upon the tissues at the point of contact, added to the electrolytic effect. The heating of the dilute acid around the platinum point in the Wehnelt interrupter is produced in a similar way.

Electrolysis of Animal Tissues.—In its relation to electricity the animal body may be considered as an electrolyte consisting of a spongy mass filled with a solution of sodium chlorid. An electric current passing through this electrolyte produces a stream of sodions (sodium cations) moving toward the cathode, and a stream of chlorions (chlorin anions) moving toward the anode. The ultimate products of electrolysis are liberated at the electrodes, and do not consist in free sodium or free chlorin. These have such strong affinities that a substitution reaction takes place in the body at the two electrodes, resulting in the liberation of free oxygen or free acid at the anode and of free hydrogen or free hydroxyl (OH) or free alkali at the cathode. The effect upon the tissues at these two points is considered later. The foregoing process undergoes certain modifications dependent upon the composition of the electrodes. If the latter are of metal and are directly in contact with the skin, metallic ions usually diffuse into the tissues from the anode. Anodal diffusion is the most accurate name for this process, which has been used therapeutically for the effect of the metallic ions upon diseased tissues; but the process has also been called cataphoresis, because the movement of the metallic ions is away from the anode, through the tissues, toward the cathode. Copper or brass electrodes applied immediately to the surface of the skin will produce a burn at the cathode from the action of the metallic ions if a current of considerable strength is applied.

Metallic ionization may be desired for therapeutic purposes, as in copper cataphoresis for hemorrhoids or fissure. More often, however, it is undesirable, and the usual method of avoiding it is by covering the metal with chamois, wadding, sponge, kaolin, or clay moistened with a solution of common salt or of sodium bicarbonate.

Some metals, like platinum, yield very few ions, and, used as surface electrodes or even introduced as needle electrodes, yield results which are due simply to the electrolytic dissociation of the tissues themselves. Passing a platinum needle electrode into a hair-follicle or piercing the skin itself with such a needle and connecting it with the negative pole of a galvanic battery while the positive pole is connected with a sponge-covered electrode held in the patient's hand, a current of one to two milliamperes will produce visible electrolysis. The tissue becomes white and swollen, and bubbles of gas are formed. The chemic effect at the negative electrode is of the liberation of H and of OH, or of free alkali, and this has a dissolving action upon albuminoid substances. If the action is long enough and strong enough, there is colliquative necrosis of the tissue surrounding the needle, and the latter becomes loosened, and when removed is found bright and free from oxid. A needle electrode connected with the positive electrode produces a somewhat similar effect upon the tissues—swelling and pallor and bubbles of gas, but oxygen and free acid are the products of electrolysis there. The result is a coagulation necrosis (from the formation of acid albumin), and the needle sticks fast in the tissues. A steel needle should never be used as an anode; the iron ion would stain the skin indelibly. Such a needle would come out badly rusted from oxidation. With surface electrodes there is a swelling and edematous condition of the skin under the cathode, due to electrolysis, and this may be more correctly called cataphorescence. At the anode, on the contrary, the skin has a tendency to contraction.

The tissues of the body form a continuous though not altogether uniform electrolyte when sponge-covered electrodes wet with saline solution are used, and the products of electrolysis are found at first in the salt solution close to the electrodes. If the current continues in one direction, a secondary effect becomes evident after a time. The great resistance at the surface of the body and the complex character of its chemic composition make the point of contact between the salt solution and the skin correspond closely with the line of separation between the water and the salt solution in the experiment below. Acid or alkaline radicles are liberated at the surface of the skin, and may produce a severe effect. Means of avoiding this are by changing the direction of the current from time to time, and by occasionally rinsing out the electrode with fresh solution. The palms of the hand are most resistant to any such effect, but the skin of any region where the epidermis is thin may be irritated or even "burnt" by the products of electrolysis. This is one reason for the employment of very large electrodes when strong currents are to be applied. A given strength of current expressed in milliamperes will produce the same amount of chemic change whether it passes through a large or a small conducting path. When the surface of contact with the skin is a large one, the cross-section of the conducting path is correspondingly large, and the products of the chemic changes are so diluted that they may be carried away by the circulation of the blood and lymph without producing an irritating local effect.

The matter is one of current density, and is similar to the difference between the slow combustion which takes place in the whole human body, and produces a certain amount of carbonic acid (CO_2) each minute without raising the temperature above 98.5° F. The same amount of combustion producing the same amount of CO_2 per minute in a single finger-tip would be accompanied by a painful and destructive burn, with a local temperature far above the normal.

An example of secondary actions is found when an electric current is passed through a solution of sulphate of copper. The salt is separated into copper, which is deposited as copper plating upon the surface of the negative electrode, and an acid radicle which goes to the positive electrode. The acid radicle combines with the hydrogen of the water in which the sulphate of copper is dissolved, and forms sulphuric acid, while the oxygen of the water is liberated as bubbles of gas. Electrolysis of a solution of sulphate of sodium furnishes the same secondary reaction at the anode, with the formation of sulphuric acid and the liberation of oxygen gas, but the secondary action takes place at the cathode also. Sodium has such powerful affinities that metallic sodium is not deposited upon the cathode, but it at once combines with the oxygen of the water, and this liberates bubbles of hydrogen gas.

Secondary products appear when the primary products are capable of reacting upon water or upon the substance of the electrodes.

The products of electrolysis appear only at the electrodes and without any apparent change in the liquid when the latter is homogeneous, but this is not the case when the current has to traverse series of different solutions.

A current may be passed through a jar containing plain water at the top and a solution of common salt at the bottom, the whole being colored by litmus. When the current passes from above downward, a red color is developed at the junction of the two liquids, indicating the liberation of an acid. Reversing the current will result in a blue color, indicating the liberation of a base or an alkali at the junction of the two liquids.

Polarization also takes place at the line of separation between the two liquids, and may be demonstrated if the original electrodes are removed after the current has been flowing for some time. The original electrodes may be removed, and another pair which are connected with a galvanometer may be placed in the two liquids. A current will at once begin to flow in the contrary direction to the original current.

Transportation of Matter by the Electric Current.—A solution of sulphate of copper in a glass vessel and an inner porous jar will tend to assume the same level in both of the jars, but if copper electrodes are placed in the two jars and a current of electricity sent through them, the liquid will be carried toward the positive pole, and will assume a higher level in that jar than in the other. The stronger the current, the greater the difference in level will be maintained.

Another striking demonstration is made by passing a current of electricity through two jars containing an anilin dye, and between which is an inverted U-shaped tube filled with gelatin which dips into both jars. Even a weak current will cause a rapid ascent of particles of the coloring-matter into one or the other arm of the U-shaped tube.

Salts which are present in very small amount or which are subjected to a very weak current are not always dissociated, but are sometimes merely transported by the current in the ways illustrated above.

In the living tissues, as in experiments upon electrolytic solutions in glass jars, the products of chemic dissociation appear only at the electrodes. In the animal body the current does not pass through a single homogeneous electrolyte between the two electrodes, but encounters membranous septa, either large or minute, which convert the path of the current into the equivalent of a series of electrolytic cells.

An experiment has been tried by Leduc, placing a rabbit in connection with an anode moistened with strychnin sulphate, and another rabbit with a cathode also wet with a solution of strychnin sulphate, the two rabbits being joined by strands of wet gauze. When the current is turned on chlorions (chlorin anions) pass from the tissues into the solution forming the anode, and strychnin cations pass from the solution at the anode into that rabbit, which accordingly develops strychnin-poisoning. The other rabbit connected with the cathode experiences only the effect of sulphions (SO_4 anions) from the cathode solution of strychnin sulphate, and of sodions (sodium cations) liberated in the tissues and traveling toward the cathode. Using potassium cyanid solution for the two electrodes, a similar effect is noted, but upon just the opposite rabbits. Here the toxic ions are cyanogen anions, and penetrate the tissues from the cathode solution.

A similar condition is found in the animal body, and the free products of electrolysis appear only at the electrodes, but there are complex chemic processes which result in the neutralization of the metallic ions by combination with tissue elements near the anode, and it is the same way with acid ions near the cathode if that electrode is moistened with an acid or a salt solution. The ions derived from either electrode do not pass through the body to the other electrode, but enter into combination with certain tissue ions, and other tissue ions liberated from these pass through the body toward the other electrode. The body, as far as the conduction of electricity is concerned, may be regarded as a mass of solution of sodium chlorid 5: 1000, and according to many observers conducts only by electrolysis and not at all by the sort of conduction, by the passage of simple electrons, which is characteristic of metals. This would mean that electricity can travel through the body at a rate not exceeding 39 meters a second, instead of at the rate of 180,000 miles a second. This retardation involves the conversion of a portion of the electric energy into heat or some other form of energy in the human body, just as surely as is the case with mechanic motion when impeded by friction or otherwise. In our electrolytic interrupters, liquid rheostats, and volt controllers a great part of the lost electric power appears as heat, and the remainder acts to produce chemic combination or decomposition. A current passed through an osmotic cell or a jar in which two liquids are separated by a permeable or a semipermeable membrane expends a part of its energy in adding to or retarding the motion of particles through the membrane. A current of electricity yields all these different forms of energy in passing through the human body. It increases or reduces all the phenomena of living tissues according to the direction of the current and its mode of application. A prolonged application probably produces chemic changes at various places in the path between the electrodes, as well as in close contact with them.

Among the direct uses of electrolysis are the destruction of the hair-follicles in hypertrichosis and of unnatural growths of various kinds, and the introduction of various materials, anesthetic and therapeutic, into the tissues.

Coagulation Caused by Electricity.—Proteid matter is coagulated by electric currents. Experiments by W. B. Hardy[1] were made with a filtered and boiled solution of egg-albumen and a current of from 10 to 105 volts, but of only $\frac{1}{1000}$ milliampere. When the solution was alkaline the molecules of albumin were carried toward the anode, with the development of opalescence and a coagulum there. The same phenomena took place at the cathode when the solution was acid.

Effect Upon the Blood.—The experiments of C. N. Stewart[2] have thrown light upon the effect of electricity upon the blood. The conductivity of the serum which has dissolved out the hemoglobin of the red cells is sometimes increased to a greater extent than at other times. The apparent explanation is that the red cell contains hemoglobin and electrolytes (salts whose solution is a good conductor of electricity) and that under some conditions the hemoglobin alone is dissolved out, and under other conditions both the hemoglobin and the electrolytes. The red cells normally contain more hemoglobin than can be dissolved in the amount of water which they contain, and it seems probable that all the hemoglobin and a part of the electrolytes are united with the stroma of the cell. It is usually easier for the hemoglobin to escape through the cell-membrane than for the electrolytes. The effect of the electric current is to alter the relations of the hemoglobin with the rest of the cell-body.

Stewart's observations go to show that the electric resistance of the blood-cells is very great as compared with that of the blood-serum, and that the relation between the electric resistance of the serum and

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[1] Journal of Physiology, vol. xxiv, p. 228, 1899.

[2] Ibid., p. 211, 1899.

that of the entire blood will give an indication of the fraction which the blood-cells form of the entire blood. This may be of value in conjunction with the usual test, which is based upon the color of diluted blood, and especially when the apparatus for making the latter test is not available.

The Effect of Electrolysis Upon the Resistance of the Body.—After the current has been flowing for a certain time the resistance is quite different from, and usually much less than, the initial resistance. This is doubtless due to the penetration into the skin of ions from the electrodes, or from the solution with which they are covered, and the skin consequently becoming a better conductor.

This property of increased conductivity under the influence of electric agents is similar to the peculiar property of the coherer in the wireless telegraph apparatus, and it is quite within the range of possibility that the human body may some day be used as part of the receiving instrument in wireless telegraphy as a laboratory curiosity. To accomplish this, the body would be connected with the two poles of a battery with an apparatus for registering the slight changes in the electric resistance of the body which would occur under the influence of the Hertzian waves received from the sending station.

The Polarizing Effect of Electrolysis Upon the Tissues.—After the current has been turned off, a considerable counterelectromotive force may be demonstrated by passing the wires from the two electrodes to a galvanometer instead of to the battery. The effect is of the same nature as in a storage-battery.

Rapidly alternating currents of small volume, like those from the ordinary faradic coil, do not produce marked electrolytic effects, and hence do not quickly change the electric resistance of the part to which the electrodes are applied. Such currents are to be used when accurate measurements of the electric resistance of the body are undertaken, but while alternating currents of the character produced by the faradic coil do not produce polarization in the sense of a difference in chemic composition and in electric potential at the two points of the body to which the electrodes are applied, they do produce electrolysis and eventually a change in electric conductivity at these points. Preliminary faradization has long been considered to lower the resistance to the passage of a galvanic current subsequently applied. By the de Watteville or combined galvanic and faradic current we produce an effect upon the tissues which permits the passage of a stronger galvanic current than would be comfortable or safe if the latter were applied alone. This may be due to the effect of the faradic current in preventing polarization of the tissues.

The tissue changes produced by the very rapidly oscillating discharges known as high-frequency currents, and those produced by the *x*-ray and by different luminous rays, are described in the special chapters upon those subjects.

It is probable that in the last analysis almost all the physiologic effects of electricity upon the animal tissues should be considered as due to electrolysis and to electric osmosis, the last referring to the passage of measurable quantities of a liquid through an animal membrane. Some of these different effects are now to be described.

Effects Upon Nerve-fibers and Muscles.—A strong current applied to the body causes, according to Herman, a movement of the myelin of the medullated nerve-fibers in the direction of the current, *i. e.*, from the anode toward the cathode. This is coincident with a depressive cathode action upon the nerve functions and a wave of electricity through the whole muscular system, which may be due to a loss of conductivity in the muscles. The effect upon the muscles is to cause contraction and perhaps paralysis, or in the case of the unstriped involuntary cardiac muscle fibrillary tremor, an uncoördinated, continuous, fluttering contraction of the ventricles, with greater than natural movements of the auricles, which is the cause of death in many cases of electric shock.

Different voluntary muscles may be made to contract by the application of electric currents directly to the muscle or directly to its motor nerve, or to the skin over the nerve or over the muscle. A knowledge of the position at which the motor nerves are nearest the surface and of the motor points of the muscles (at which the nerve enters the muscle) is important in electrodiagnosis or therapy. The involuntary muscles of the intestine and other parts may be caused to contract or relax by electric currents. Tissue cells in different parts of the body may be stimulated to activity and growth by means of appropriate electrization; the growth of the hair may be increased. It acts, therefore, upon the trophic fibers of the nerves as well as upon the sensory and motor fibers.

Effects Upon Glands.—Currents of moderate strength increase or diminish the secretion of different glands through an effect upon the nerves regulating their blood supply and those regulating the functional activity of their parenchymatous cells. The circulation in different parts of the body is increased or diminished by electrization affecting the vasomotor nerves and the heart.

Effect Upon Special Senses.—All the different special senses may be excited by electricity. The patient may see flashes of light produced by the application of a current to the temples, and the sense of smell, taste and hearing, and of tactile and thermal perception may be excited. This may occur independently of actual noise or light or substance with a recognizable taste that may be produced by the current. For instance, the sense of taste may be excited by electrization of the outside of the neck or the forehead.

Influence of Current Density.—The current density has very much to do with the effect of electrization, and this becomes reduced as the distance from the electrodes increases. Internal organs, like the brain, receive from an external application only a very widely diffused current, and hence are only slightly affected by currents of considerable strength. Electrodes applied directly to the substance of the brain produce a very decided effect with very much weaker currents. It is the same in regard to the heart. Fibrillary tremor is excited by a current of one or two milliamperes from electrodes applied directly to the cardiac substance; while a current of twenty milliamperes will not produce dangerous effects if applied through electrodes placed on the surface of the chest.

Effect of Electrization of the Eye.—One electrode from a galvanic battery being applied to the nape of the neck and the other over the eye, visual sensations, like flashes of light, are produced when the current is turned on and off. The effect of the closure of the current is most pronounced when the current flows from the brain toward the eye. The effect of breaking the current is most pronounced when the current is from the eye toward the brain, that is, when the anode is placed upon the eye.

An electrode being applied to each side of the eyeball and a continuous current flowing, a sensation of light and color will be produced. The half of the field of vision controlled by the part of the retina nearest the anode appears greenish, while that perceived by the part of the retina near the cathode appears brighter and bluish. Different persons see various forms and colors under the influence of electric currents applied to the eye in these or similar ways.

Flashes of light are seen when an electrode is applied to the forehead and another to the epigastrium.

Auditory Effects of Electricity.—One electrode being applied near the ear and the other to some indifferent point, sensations of sound are produced by the galvanic current. The effect of the cathodal closure is the strongest, but a sound is also noted at the opening of a stronger current when the anode is applied to the ear.

Influence of the Position of the Electrodes.—The position of the electrodes has a great deal to do with determining the density of the current passing through different organs, and hence regulates the physiologic effect of the current. Electrodes held in both hands send a much smaller proportion of the current through the brain than is the case when one electrode is at the top of the head and the other at the feet. Electrodes placed at both sides of the head are thought by some observers to send a sufficient current through the brain to produce a therapeutic effect, while others believe that the current is too widely diffused and that much of it follows the homogeneous conducting layer afforded by the scalp, and passes around the skull and not through it. Without trying to decide this question it may be stated that cerebral conditions are apt to be much more influenced through the vasomotor and other effects of electric currents upon the cranial, spinal accessory, and sympathetic nerves than by the direct effect of the portion of the current which can be sent through the brain itself. When the electrodes are placed very near each other upon the surface of the body, the resistance at the points of entry and exit of the current greatly exceeds that of the portion of the body between these points, and the current almost all follows a short straight line with scarcely any diffusion. Placed close together, even over the motor point of a muscle, a fairly strong current may not excite a contraction.

A daily example of this strictly local action of the current when the electrodes are applied close together is afforded by the electrician when testing a 110-volt electric-light socket. To see whether there is current present, he moistens his finger and puts it inside the socket, thus making contact with the positive and negative terminals. If the current is there, he gets a pretty sharp sensation in the finger, but this is not very disagreeable and not dangerous. It is quite a different matter from the experiment tried by the author, of holding a metal object in each hand and then placing these objects in contact with the terminals of the 110-volt direct circuit. As the contact was made, a sense of severe shock was experienced, accompanied by a violent involuntary muscular contraction which jerked the arms downward and backward, and caused the metal objects to be thrown back across the room and to make a dent in the woodwork there. It is an experiment which he would not advise any one to repeat, but it goes to show that accidental contact with both the bare conductors carrying the 110-volt direct current will not necessarily produce serious results. The fact that the electrician usually moistens his finger before testing for current indicates that the resistance at the point of accidental contact with bare conductors would usually be so great that no very strong current would pass through the body. In the author's experiment the conditions were different: the electrodes were constituted by large metallic objects held in the closed hand, the large surface and perfect contact reducing the resistance to a minimum.

Touching one bare 110-volt direct current conductor with the dry finger gives no appreciable sensation under ordinary circumstances. If, however, the person is standing on a floor which is a good conductor, iron, for example, a shock may be received of the same nature as that in the author's experiment, but of much less severity. This is due to the fact that it is practically impossible to insulate a dynamo from the earth, and consequently a circuit is formed when a complete conducting path is provided from either terminal to the earth. A person standing on a wooden floor with perhaps a woolen carpet is pretty completely insulated from the earth for currents of this tension.

A more powerful current may be applied by means of needle electrodes close together for the destruction of tumors of the breast than could be safely applied if the electrodes were placed at a distance and in such positions that the current would traverse vital organs. Still, very strong currents are employed by some operators in cataphoresis. Massey has the patient lie upon a large kaolin or clay cathode placed under the sacral and gluteal region, while the positive wire terminates in a number of sharp points of zinc amalgamated by mercury. The current is gradually turned on, and a maximum of 200 or 300 or more milliamperes of the direct current is allowed to flow even if the anode points are thrust into a growth on the face. The heart's action is watched, but, as a rule, is not materially affected. An alternating current or a direct current with sudden variations in strength would produce disastrous results if applied in this way.

Accidental contact with both terminals of a high-tension circuit at points close together on the surface of the body may be followed by only local injury, whereas contact with one terminal alone, with conduction through the body to the ground, or with both terminals at distant parts of the body, might be fatal.

It is, however, not a universal rule that a high-tension current is harmless if applied by electrodes close together, as described above.

Influence of Voltage and Amperage.—The voltage or tension of the current often has a controlling influence over the strength or amperage of the current which passes through the body from one electrode to the other, and has, for this reason, a great effect in determining the effect upon the tissues. This is true of currents derived from a source of sufficient quantity to furnish a current strength in amperes equal to the voltage divided by the resistance (Ohm's law). Sources of very high potential and very small quantity, such as the static machine, do not send a current through the body equal to anything like the voltage divided by the resistance. A hand may throw a solid metal ball at a certain velocity, and the momentum of the ball may be such as to considerably damage anything it strikes against. The same hand moving at the same rate of speed will impart the same velocity to a cork, but the latter will probably not damage anything it strikes. The high potential is capable of sending great amperage through the body, but does so only when the necessary quantity is supplied. This is the case with currents immediately from large dynamos, or as modified by step-up transformers. It is really the combination of tension and quantity—that is, energy or the number of watts—that largely determines the effect upon the tissues.

Effect of Static Electricity.—The static spark produces a different effect according to whether it is applied singly or as a continuous stream of sparks upon the same spot. In the first manner it produces an effect which is due to molecular vibrations and not due to immediate visible changes in the tissues. The effect is one of stimulation of the activity of the cells of the part to which it is applied, and of the central nervous system and of the vasomotor nerves. Therapeutically, isolated static sparks are beneficial where there are lowered arterial tension and nervous debility, and in painful conditions dependent upon them. It is not generally beneficial in conditions of irritation and painful affections dependent upon them. High-tension electricity appears to be preferable for debility and depression, while low-tension electricity is preferable for irritative conditions.

A stream of static sparks applied to one spot will prove very painful at first, but later produce a benumbing effect. There is redness, followed by blanching and swelling of the skin. If the application is very prolonged and severe, it produces superficial destruction of the skin.

Static sparks cause a muscular contraction which is quite valuable diagnostically, especially when they are applied singly and their tension and quantity are accurately gauged, as is the case with condenser discharges. The latter, however, are more often employed for diagnosis or treatment with a much smaller voltage than characterizes the output of the static electric machines.

Static insulation produces about the same effects as the static spark, without any of the disagreeable effects of the latter. It is not quite so strong a stimulant, but is preferable for a great many cases. The static breeze produces a local and general tissue stimulation without any uncomfortable symptoms. Morton's wave current and the static induced currents produce similar effects, but with more sense of shock and muscular contraction. All very high-tension discharges with very

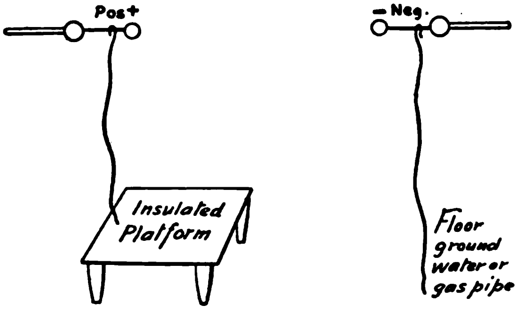

Fig. 207.—Static insulation.

small quantity may be considered to produce effects by means of vibration of the tissue-cells, rather than by transportation of ions through the tissues and liberation of chemic products at or near the points of contact.

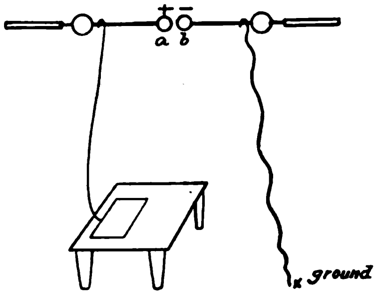

Fig. 208.—Morton's wave current. Patient's feet on metal plate. Regulate by *slowly* separating + and −.

Effect of High-frequency Currents.—The different applications grouped under the name of high-frequency currents do not produce muscular contraction or electrolytic effects corresponding to the quantity of electricity passing to the body, and apparently passing through it. This is because the transportation of ions through the semipermeable membrane formed by the human body cannot keep such rapid rhythm as these currents. The conducting wires transmit the to-and-fro currents by metallic conduction, simple transmission of electrons without the transportation of ions (particles charged negatively by an extra number of electrons, or positively by deprivation of electrons), and subject only to the ordinary ohmic resistance and to impedance due to induction. The human body in its relation to these excessively rapid oscillations may be considered as a capacity which is alternately charged and discharged without much current passing through it. It may be compared to a balloon with a large opening, through which air is blown in and the balloon inflated and then allowed to collapse, an opening at some other point being so small that it does not prevent the balloon from being blown up, and even during its collapse allows very little of the air to escape in that direction. To make the analogy complete, we should have two large openings at opposite sides of the balloon, alternately one and then the other being closed during the rush of air into and out of the balloon through the other large opening. The fact that the high-frequency current does not in great part pass through the body has lead to the supposition that it is found, like static electricity, chiefly on the surface of the body. This does not appear to be the case, and there is not the same reason for it as with static electricity, where the voltage is much higher and the repulsion of the charge is much greater. It has been demonstrated that high-frequency currents have an effect upon deep tissues.

Pathologic Effects Upon Workers in Electric Power-houses.—The enormous power-houses in which the natural power from water pressure, as at Niagara Falls, is converted into electricity, and other power-houses where the electric current is transformed from the very high transmission tension of 20,000 volts or more to the utilization tension of 550 or 110 volts, present abnormal conditions for their workmen. Lines of force which will produce a perceptible effect upon any suitable recording instrument surround these great dynamos and transformers and must have their effect upon the organism. We are all familiar with the magnetizing effect of such environments upon a watch. Then there is the ozone generated by the visible and invisible electric discharges. These electric discharges produce the ultraviolet and possibly other radiations. All these various factors are operative, though they produce no perceptible effect upon a person who visits such a power-house for only a few minutes. Millener, of Buffalo, N. Y.,[1] has observed bad effects in 22 cases among the workers, the symptoms being pallor, loss of appetite, abdominal pains, indigestion, and constipation. In some cases it was noted that if the man ate his lunch at the power-house or returned to the power-house directly after going out to lunch, indigestion followed, while if the lunch was eaten at home and the man did not return to the power-house for a considerable time, no distress was experienced.

The power-houses are perfectly ventilated and drained and warm and clean, and there is sufficient exercise to keep the men in good condition physically, so that the conclusion is that the symptoms are due to electricity. Alternating currents passing through the coils of wire in the fields and armatures of these enormous machines produce expanding and contracting lines of force which we should expect to be more effective in influencing the human organism than a continuous current. There are no recorded observations to decide this point, but Millener adduces the fact that milk rapidly sours in a power-house where high-voltage alternating currents are present. He also states that in butter factories machines run by an alternating current motor cannot be used because the cream sours, while no such objection is found to the use of a direct current motor. The souring of milk by lightning is another example of the effect of electricity upon organic substances.

The only protection against these deleterious effects at present known is to take frequent vacations from the work.

The Effect of Working in the Room with *x*-Ray Coils and High-frequency Current Apparatus.—The most powerful apparatus of this kind takes only a very small fraction of the output of a dynamo, and the influence pervading the room is correspondingly weaker. Of the many patients and physicians who have visited the author's office, not one has ever complained that his watch had been magnetized, and the author's own watch keeps perfectly correct time. Then, again, the author's experience of being constantly in the treatment room, with no vacation of more than five days at a time in seven years, and never missing a day's work on account of personal illness, indicates an absence of deleterious effect from long exposure to the influence of apparatus of this capacity. This, however, does not mean that one can remain exposed to the *x*-ray day after day with impunity. One must certainly be shielded from the rays from an *x*-ray tube, either by some shield of lead or other opaque material, or by always remaining in an adjoining room. Practically, nothing is impervious to electromagnetic induction or to the so-called lines of force generated by induction coils, etc., and it is fortunate that the influence from those of a suitable capacity for *x*-ray and electrotherapy seems to be beneficial rather than harmful. However, long exposure to the *x*-ray itself is very harmful, as is stated more fully elsewhere in this book.

The effect of high-frequency currents upon the tissues is very important, and is found in a separate chapter upon that subject.

Effects of Condenser Discharges.—The most valuable observations are those which determine the single discharge necessary to produce a muscular contraction, and then the frequency with which that discharge

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[1] American Medicine, August, 1906, p. 255.

must be repeated in order to produce tetanus. These vary in different muscles and in different animals.

A suitable arrangement of apparatus is shown in Fig. 209.[1] The electrodes E and E are applied to the animal experimented upon. One is connected with one armature of a condenser M, having a capacity of $\frac{1}{10}$ microfarad. The other electrode is connected with a pivotal point, O, of a fine platinum wire, which carries a small iron hammer at one side and an opposing spring at the other side of the pivot. When the hammer is attracted by the action of an electromagnet, the point N makes an electric contact with a cup of mercury, and through that with a source C, of variable potential. The animal and the condenser are then charged to the required potential, and the quantity of electricity may be calculated from the voltage and the fixed capacity of the condenser. The capacity of the animal is fixed also, and is only a small fraction of the capacity of the condenser. It does not affect the calculation. When the electromagnet ceases to act, the spring breaks the contact at N and makes a contact with another mercury cup at L, and thence to the earth. The condenser is then discharged through the animal between the electrodes E and E.

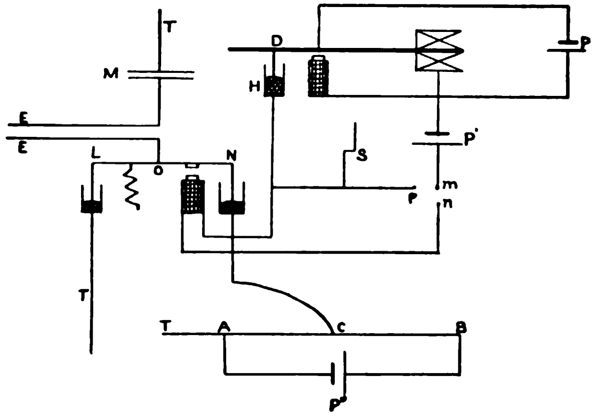

Fig. 209.—Arrangement for rhythmic condenser discharges.

The source of variable potential consists of a battery P'', the two poles of which are connected with the extremities of a resistance wire, AB, one end, A, of which is grounded. There is a sliding contact, C, and by moving this the potential communicated to the animal and the condenser is varied from zero when the contact is at A, to the full potential of the battery when the contact is at B.

The electromagnet above alluded to has a separate battery P, the current of which is made and broken at D, which dips into a mercury cup. This point just touches the surface of the mercury when at rest, and as it moves an equal distance up and down, the duration of each contact is the same as that of the interval when no current is flowing.

The point D is at the end of a vibrator of adjustable length, and hence of adjustable rate of vibration under the influence of its own

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[1] Carvallo and Weiss, Journal de Physiologie et de Pathologie, 1899.

battery, P, and its own electromagnet. There is a separate electric signal which may be brought into this circuit by turning the switch from m to p, instead of from m to n. The signal acts synchronously with the motions of the vibrating interrupter and enables one to count the latter.

A simpler arrangement is used when single or isolated condenser discharges are applied in electrodiagnosis or electrotherapy. One armature of the condenser C (Fig. 210) is grounded; the other armature is connected with the pivotal point of a Morse telegraphic key. In the normal position a spring causes the Morse key to make contact with a wire leading to one pole of a battery, the other pole of which is grounded, and in this position the condenser quickly becomes charged to its full capacity at the potential of the battery. Depressing the Morse key breaks the connection with the battery and makes a connection with a wire leading to the nerve or muscle, from which another wire leads to the ground. The condenser discharges through the animal and the ground, as they form a complete circuit between its two armatures.

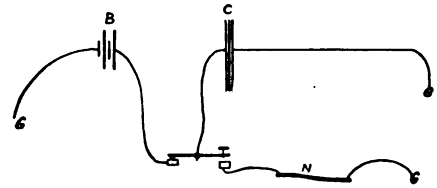

Fig. 210.—Connection for condenser discharge through a nerve: B, battery; C, condenser; G, different ground connections; N, nerve.

Condensers for diagnosis or treatment have a capacity varying from $\frac{1}{100}$ to 2 microfarads.

The condensers used in the arrangement described above are of large capacity, having 1000 or several thousand square inches of condensing surface, and are charged to a potential of 30 to 100 or 200 volts.

Effects of Leyden-jar Discharges.—*Condenser Discharges at High Potential from the Static Machine.*—These are the currents introduced by Morton, and in the usual method of application the inner armatures of the jars are connected with the two poles of the static machine (Fig. 211). The outer armature of one jar is grounded, while that of the other jar is connected with a metallic electrode applied to the patient. The patient is not insulated. The discharging rods of the static machine are close together. The two inner armatures discharge across the spark-gap at regular intervals, and simultaneously a condenser discharge occurs between the outer armatures through the

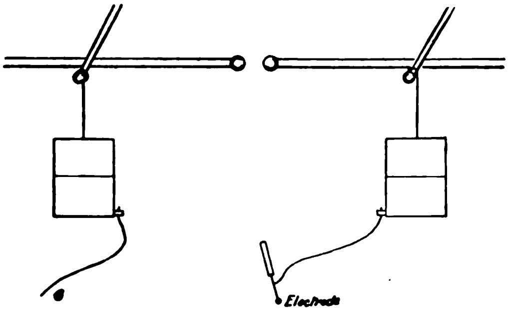

Fig. 211.—Arrangement for Leyden-jar discharge from static machine.

patient's body and the earth. In this case there may be high-frequency oscillations, but the chief noticeable effect is from the discharge of the Leyden jar at a comparatively low rate of frequency, as indicated by the successive sparks, and consists in muscular contractions and a sense of shock which is disagreeable if the spark-gap is long, and hence the condenser discharges are severe.

The effects of condenser discharges of different quantity, potential, and frequency are naturally variable. The factor of quantity is found by simply multiplying the capacity of the condenser by the voltage to which it is charged, $Q=CV$. The energy required to charge the condenser is a different matter, however. It is equal to $\frac{1}{2}CV^2$, and this is also the effective energy that is liberated when the condenser is discharged.

The Stimulation of Muscular Contraction by a Single Condenser Discharge.—The object of numerous experiments has been to determine the relation between the voltage and the capacity required to produce contraction. A condenser of a fixed capacity is used, and electrodes applied to the exposed nerve are connected, as shown in Fig. 210. The condenser is at first charged and discharged at a very low potential, which is gradually increased until a minimal muscular contraction is produced. The capacity of the condenser and the voltage are recorded, and then the same experiment is tried with a condenser of a different known capacity, either greater or less than that of the first. It is found that the voltage to which different condensers must be charged in order to produce equal muscular contractions does not vary inversely as their capacity, as would be the case if the same quantity of electricity were discharged in each case. The conditions required correspond more nearly to those in which the effective energy is the same, so that in each case $\frac{1}{2}CV^2$ amounts to the same number of joules. The required voltage, therefore, varies approximately inversely as the square root of the capacity. If a condenser of a certain capacity must be charged to a potential of 20 volts in order to produce a minimal contraction, the same effect would be produced by a condenser of four times that capacity, charged to a potential of about 10 volts, or by a condenser of one-fourth that capacity, charged to a potential of about 40 volts. These proportions hold good within quite wide limits, but not for extreme cases. Thus, a single discharge from the largest available condenser fails to give muscular contractions when charged to a potential of only one volt. Even in this case, however, a rapid succession of condenser discharges will produce muscular contraction. This does not appear to be due to a lessened resistance of the body, for this apparently does not result from successive condenser discharges. The latter produce hardly any electrolytic or polarizing effect, the increased stimulation being due to an overlapping of the successive waves of stimulation, with a consequent cumulative effect. This is entirely analogous to the fact that the height of the contraction from a single stimulation by the galvanic current is considerably exceeded when a number of such stimuli are applied in rapid succession. The small resistance of the body may, however, be modified by the previous passage of a continuous current for some time, and then it will be found that a condenser discharge will produce a greater effect than it would have produced previously.

The physiologic effect of a single condenser discharge is clearly modified by the useful duration of the discharge, but there is a question as to this being called the law of stimulation by condenser discharges, as suggested by Cluzet,[1] and the Lapicques have made a series of experiments to determine this point and with negative results.[2]

The duration of the discharge of a condenser is, however, considered by Lewis Jones[3] as affording the best numerical expression for the contractility of a muscle to this form of stimulation. (See also page 382.)

Cluzet, Dubois, Zanietowski, Hoorweg, Cybulski, Weiss, and Prévost and Battelli have made accurate experiments with condenser discharges. This must be regarded as a new and valuable addition to the means of electrodiagnosis and electrotherapy.

The effect of a condenser discharge may be modified by introducing an additional resistance or inductance or capacity in the circuit, the effect being to reduce not so much the intensity, as the duration of the discharge. The length of the wave of stimulation makes the same difference with condenser discharges as it does with the make and break of a continuous current.

Muscular Contraction from Rapidly Repeated Condenser Discharges.—Applying two metallic electrodes to the sciatic nerve of a frog, tetanus is produced by discharges of the same condenser, charged to different voltages and at a different rate of speed.

Frequency per second.	*Voltage required (Carvallo and Weiss).*
14	0.0300
15	0.0250
19	0.0100
21	0.0050
23	0.0045
30	0.0035
40	0.0025

From this experiment it will be seen that the voltage required to produce tetanic contraction is very much less for rapidly than for slowly repeated discharges.

Discharges at the rate of from 25 to 30 a second produce the most powerful contraction. Such condenser discharges produce effects which are very similar to those of the faradic current, but they can be much more accurately measured and applied. The same thing is true of single condenser discharges as compared with isolated induction shocks.

Condenser discharges have been observed by Rollet to produce the same effect upon the blood as other forms of electricity. He has found that Leyden-jar discharges may clarify the blood. The blood would then consist of a transparent red liquid in which float colorless and transparent cells whose hemoglobin has been dissolved out by the blood plasma. This he found takes place even when the heating effect of the electric discharge is eliminated. Under other circumstances, as where a thin layer of blood is subjected to a condenser discharge, the amount of heat generated is amply sufficient to account for the clarifying of the blood. Max Cremer[4] considers the thermal element as the chief one in all cases.

This clarification, if it affected any considerable portion of the

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[1] Comptes rendus de la Société de Biologie, July 21, 1905, p. 161.

[2] Ibid., July 1, 1905, p. 63.

[3] Archives of the Roentgen Ray, May, 1913, p. 454.

[4] Zeitschrift für Biologie, 1904, vol. xlvi, pp. 77 and 101.

blood in the circulation, would be of vital importance. The property of carrying oxygen in loose combination from the lungs to the tissues, and carbonic acid from the tissues to the lungs, is practically lost by the hemoglobin when it is dissolved out of the red blood-cells. It will be remembered that this is the principal reason why salt solution is used for infusion into the veins after hemorrhage instead of plain water. The latter would dissolve the hemoglobin and defeat the very object of the infusion by diminishing the oxygen-carrying power of the blood.

In regard to electricity, however, it is not to be supposed that this clarifying effect is produced upon the blood in the living body to such an extent as perceptibly to affect any vital function.

DuBois-Reymond's Four Laws of Electric Stimulation.—1. The effect is proportional to the strength of the current or amperage which actually reaches the muscle, nerve, or other organ.

The strength of the current which reaches the organ to be stimulated depends partly upon the source of the current and partly upon the position of the electrodes. Diffusion in all directions greatly reduces the strength of the effective current unless one of the electrodes is applied directly over the organ at a place where the latter is quite near the surface. The motor points for stimulation of the different muscles are examples of the greatest effect.

2. The effect is proportional to the rapidity of the change in the strength of the current.

3. The effect is a polar one, starting from the point or points to which one or both of the electrodes are applied.

The polar effect is evidenced by the swelling from muscular contraction which takes place in a striated muscle at the cathode when the current begins, and at the anode when the current is turned off.

The polar effect upon unstriated muscle is evidenced by a relaxation of their normal tonic contraction at the anode during the passage of the current, and at the cathode when the current is turned off.

The polar effect upon a nerve is a wave of stimulation starting from the cathode when the current is turned on or its strength is increased, and starting from the anode whenever the current is turned off or its strength is diminished.

4. The cathodal closure effect is stronger than the anodal closure effect.

DuBois-Reymond's Law of Electric Stimulation by Variable Currents.—Expressed in differential calculus, $e = \text{const.} \frac{dc}{dt}$, the effect is equal to a certain constant multiplied by a differential of the current divided by a differential of the time.

This law must be modified for application to different forms of current.

The opening induced current from a faradic coil is not opposed by self-induction, and is more effective than the closing induced current. True sinusoidal induced or alternating currents which are symmetric in both directions are difficult to obtain, and so condenser discharges have been used in testing the validity of the law. Cybulski and Zanietowski, Hoorweg, G. Weiss, and Lapicque have obtained widely different results.

CV is the quantity of electricity contained in a condenser of a certain capacity, designated as *C*, which is charged to a potential designated as V, and $\frac{1}{2}CV^2$ is the energy required to charge it and liberated by its discharge.

Prévost and Battelli have found that the condenser discharge necessary to produce a fatal effect is determined by the energy of the discharge, or $\frac{1}{2}CV^2$.

Hoorweg[1] has found as the result of many experiments that the voltage to which a condenser of a given capacity must be charged in order to produce a minimal muscular contraction by its discharge may be expressed by the formula—

$$\mathrm{V} = \mathrm{aw} + \frac{\mathrm{b}}{\mathrm{c}}.$$

The quantities b and c are constant, and a is found from the formula,

$$\mathrm{E} = a_0,\ i\ e^{-Bt},$$

and in this equation e is the base of the natural logarithm. The quantity a_0 is equal to E when $t = o$. This quantity a_0 is the voltage at which minimal contraction takes place with a constant current.

MUSCULAR CONTRACTION RESULTING FROM ELECTRIC STIMULATION

This may be produced by stimulation of the muscle itself, or of the termination of the nerve in the muscle, or of the motor nerve at any part of its length, or of the brain or spinal cord, or reflexly by the stimulation of some other nerve.

An example of this effect of the electric current is seen whenever electrodes are held in the two hands, and the muscles of the hands and arms contract under the influence of a faradic current.

Our knowledge of the nature of this effect is based very largely upon experiments on the nerves and muscles of recently killed animals.

The very first discovery of the physiologic effect of electricity was made by Galvani, who found that when a pair of frog's legs were hung up where the toes would touch a metallic surface, the muscles of the thighs immediately contracted and the toes were drawn away from the metal. The muscles relaxed again, allowing the toes to reach the metal surface, and contraction again ensued. This went on for a considerable period of time, but the contractions gradually became weaker and finally ceased.

The frog's leg, with its natural saline moisture, the object from which it was suspended, and the metallic surface touched by the toes formed a voltaic cell whose current passed through the limb and made the muscles contract. The toes being drawn away from the metal, the circuit was broken and the muscles relaxed.

A Complete Neuromuscular Preparation.—This may consist of a frog's body, prepared in such a way as to enable one to make accurate observations with electric stimuli. The frog's body is cut across at the level of the middle of the abdomen; the skin is stripped from the legs and the lower part of the body. The lower part of the spinal column is exposed by slight dissection, and so is the entire length of both sciatic nerves. The upper part of the preparation is fastened to a stationary part of the table, while the foot, or, in some cases, the separate tendon of the gastrocnemius muscle, is fastened to some movable object like

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[1] Pflüger's Archiv., vol. lii, p. 87, 1892.

a weight or lever. The latter may be connected with a myograph or apparatus to register the contraction or elongation of the muscle.

A Simple Neuromuscular Preparation.—This is a muscle with its motor nerve normally attached to the muscle, but the whole preparation dissected out in such a way as to be used for observation on the muscular contraction produced by stimulation of the motor nerve. These portions may or may not be completely removed from the body. If they are not removed, the animal is alive in some cases, and then the normal blood-supply to the nerve and muscle may be left undisturbed or may be cut off by ligature of the proper blood-vessels. In any case the upper part of the muscle is stationary, while very often the tendon is separated and attached to a myograph.

Maintaining Circulation in a Neuromuscular Preparation.—The circulation in the muscle may be continued by leaving its blood-vessels uninjured, or it may be cut off. The latter results chiefly in an increased susceptibility to fatigue after electric stimuli and a less ready recovery from fatigue.

The Use of Curare.—Voluntary motion of a living muscle under experimental observation may be prevented by the use of curare, which paralyzes the terminal plaques of the motor nerve in the muscle itself or by destruction of the spinal cord. The latter can be done quite readily by thrusting a needle into the vertebral canal behind the head.

THE MYOGRAPH

The Myograph.—In its simple form (Fig. 212) the myograph consists of a lever to which the free end of the muscle is attached and a revolving cylinder upon whose surface the movable point of the stylet traces a line.

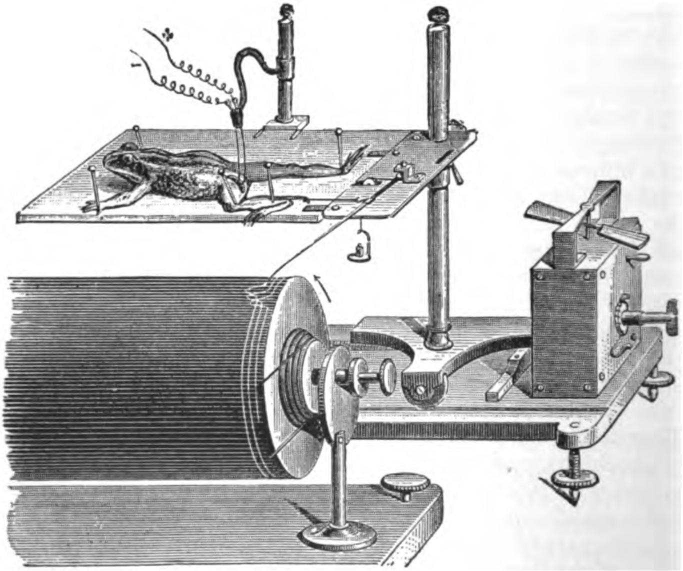

Fig. 212.—Simple myograph in operation.

Isotonic Contraction.—Isotonic contraction is shortening of a muscle against a uniform resistance. The resistance in Fig. 213 is the weight of the lever, and is practically the same in all conditions of the muscle. The muscle is connected with the lever at a point quite distant from the fulcrum or axis, and is consequently able to shorten considerably under any influence that causes it to contract with sufficient power to raise the weight of the lever. It is upon this principle that myographic records are usually made.

Isometric Contraction.—This has reference to the traction force exerted by a muscle both ends of which are fastened to stationary or practically stationary objects, so that the muscle cannot shorten to any considerable extent. A myograph in which the muscle is connected with a part of the lever very near the fulcrum will register isometric contraction if the upward motion of the lever is opposed by a spring whose pressure is properly graduated (Fig. 214). This method has not been practised to any extent.

Vertical distances on an isotonic myographic tracing show that the muscle has shortened to certain extents, the shortening being opposed by a uniform weight. On an isometric tracing vertical distances indicate certain strengths of traction (equal to sustaining certain weights) on the part of a muscle which is not permitted to shorten materially.

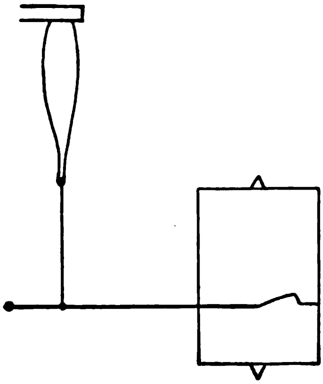

Fig. 213.—Simple myograph registering isotonic contraction.

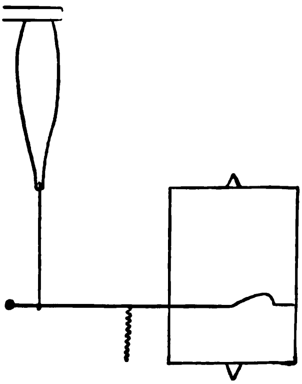

Fig. 214.—Simple myograph registering isometric contraction.

A sheet of paper wrapped around the revolving cylinder receives the tracing made by the movable point. Or a long strip of paper is unrolled from one cylinder and rolled on another one while the registering point rests upon the moving strip of paper (Fig. 215). The cylinders revolve by clock-work actuated by a spring or a weight, and the speed of their motion may be regulated according to the rapidity of the changes it is desired to register.

Marey's Drums.—A pair of these constitute a means of transmission of the motion of the lever to another one at a distance by means of pneumatic pressure. These are not required when it is convenient to have the neuromuscular preparation or living animal experimented upon in close proximity to the registering cylinder. This is frequently not the case. The part experimented on may be movable or the arrangements for the experiment may be complicated. Then, again, it is often desired to register several different tracings on the moving strip of paper, and it may be impossible to group all the different elements near the revolving cylinder. The additional tracings most often required are those registering the units of time and the application of the electric current. Other tracings sometimes made show the electric currents arising in the nerve and muscle in consequence of stimulation.

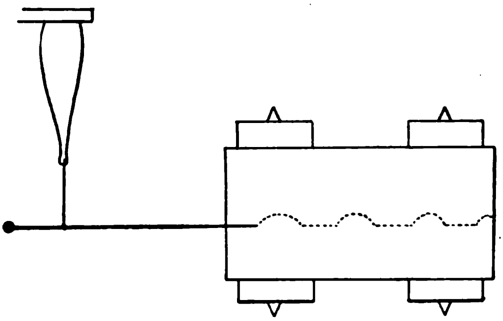

Fig. 215.—Myograph with long strip of paper unrolling from one cylinder on to another.

Marey's drum (Figs. 216–218) is a flat, round box of sheet metal sealed air tight by a sheet of rubber over the top and with an opening at the bottom where a short tube forms a connection for a rubber tube leading to a similar drum which may be several feet away. One circular side,

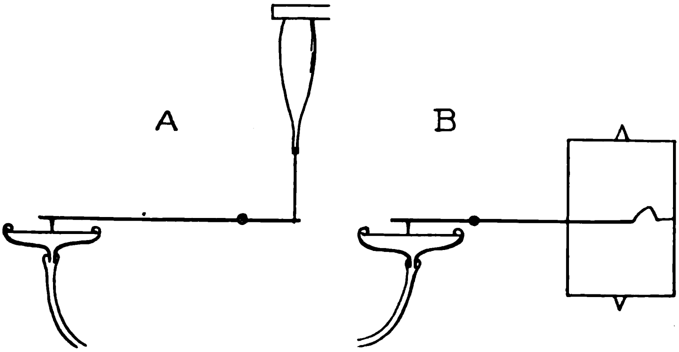

Fig. 216.—Marey's drums: *A*, transmitter; *B*, receiver.

or what would be called the head of the drum, is of soft rubber so thin as to be perfectly elastic. It is upon this that the force of the lever is brought to bear when the muscle contracts. This compresses the air in the drum, and the compression is communicated to the air in the other drum, causing motion of its head and of the registering lever connected with it. The transmission is effected practically instantaneously, being at an average rate of 280 meters a second. Several of the receivers may be grouped near the registering cylinder, and each one trace a separate line upon the chart, recording the impulses applied to the transmission drums connected with different elements of the experiment. The latter may be set up in separate parts of the room if desirable.

Marey's drum may be used to study contraction in uninjured human muscles. The drum is held against the lateral surface of the limb by a gutter-like strip of sheet metal which is bandaged over it. When the muscle contracts and swells, the latter motion is transmitted through the Marey drums to the registering apparatus.

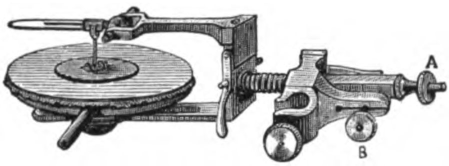

Fig. 217.—Marey's drums. Detail of transmitter or receiver.

Time Registration in Myographic Charts.—This may be done in the simplest cases by noting the time of starting and stopping the revolving cylinder. Horizontal distances on the chart indicate periods of time which can be approximately calculated.

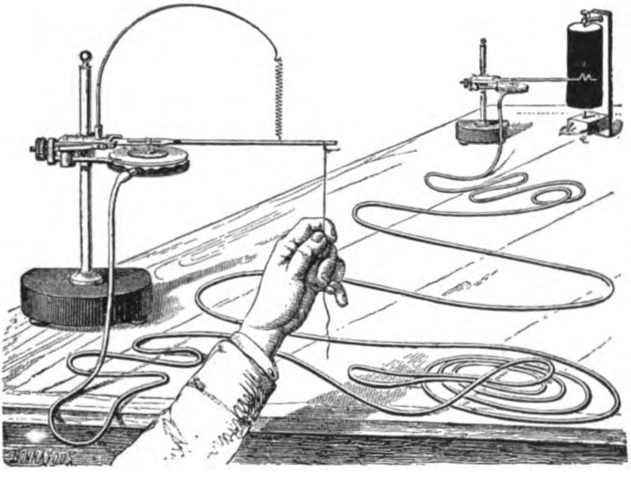

Fig. 218.—Marey's drums. Operation of complete apparatus.

Means of making a tracing of the time units upon the chart while the other tracings are being made are required for all exact observations. This is done by a movable point, which may be actuated through the medium of a pair of Marey's drums, or which may be the end of a lever moved directly by the timing apparatus.

The Timing Mechanism.—This consists of a Desprez electric signal in which an electromagnet acts upon one end of a lever, and of a battery and a means of making and breaking the electromagnet circuit at measured intervals of time. This interrupter may be a pendulum, or metronome similar to the timing instruments used by pianists, or it may be a tuning-fork.

The Pendulum and Metronome Interrupters for Time Charts.—These are suitable for cases in which the time units to be recorded are seconds or a large fraction of a second. As the pendulum swings to and fro under the influence of clock-work, which is not shown in the diagram (Fig. 219, A), the contact is made and broken. Each time that the battery circuit through the electromagnet is completed its armature is attracted and it is this motion which is traced upon the chart. The rapidity of the to-and-fro motion of the metronome (Fig. 219, B, and 220) may be regulated so that the signals occur at intervals of from one-tenth to one second. Those of the pendulum are subject to about the same

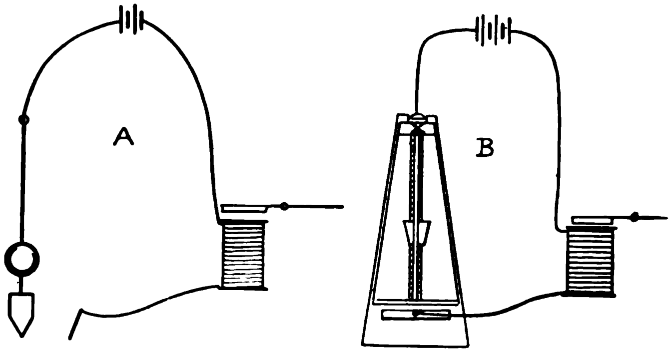

Fig. 219.—*A*, Pendulum interrupter; *B*, metronome interrupter.

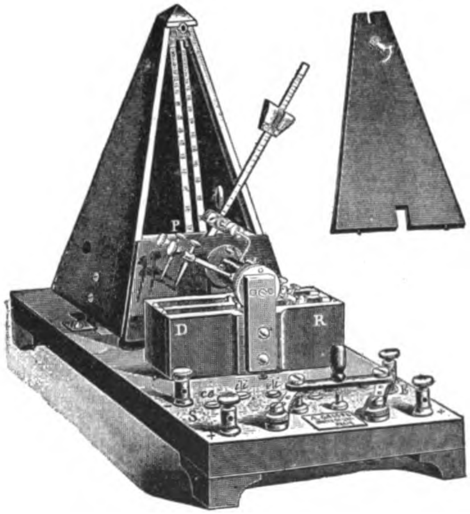

Fig. 220.—Metronome interrupter for galvanic currents.

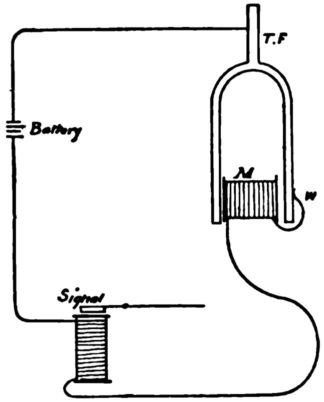

Fig. 221.—Tuning-fork (*T. F.*) and Desprez electric signal (*Signal*) for time registration.

regulation. This is accomplished in each case by changing the distance of the movable weight from the axis.

The Tuning-fork or Diapason as a Time Index with the Myograph.—The handle of the tuning-fork (Fig. 221) is securely fixed, while the prongs are free to vibrate. When at rest, one of the prongs is in contact with the wire, *w*, and completes an electric circuit through the battery, the electric signal and another electromagnet, which is placed between the prongs of the tuning-fork. This electromagnet attracts the prongs of the tuning-fork and breaks the contact. The magnetism disappearing with the cessation of the current, the prongs of the tuning-fork again diverge, and the contact is reëstablished. This is repeated with a rapidity which depends upon the natural rate of vibration of the tuning-fork, and this varies with different tuning-forks; and the same tuning-fork may be made to vibrate faster or slower by fastening a heavier or a lighter weight at a greater or less distance from the end of the prongs. The vibration rate employed is from one-tenth to one-two-hundredth second, most often one-one-hundredth second.

Desprez's Electric Signal (Fig. 221).—This is a little apparatus which may be placed close to the moving sheet of paper in the myograph, and traces the units of time upon it. There is a tiny electromagnet which acts upon an armature. The latter is of very light weight, and is pivoted upon an axis which is provided with a stilet which traces a line upon the moving sheet of paper. The electromagnet and armature are both made of very pure soft iron, to prevent any permanent magnetism, but even then the armature may not be instantly released on account of a trace of permanent magnetism. A sheet of paper interposed between the magnet and the armature will prevent this. A delicate spring draws the armature away when the current is not flowing through the electromagnet. The range of motion is very slight—the point of the stilet moves only about 1 mm., or .25 inch, just enough to make a perfectly distinct break in the horizontal line traced by the stilet when at rest. The electric signal is so sensitive and rapid in action that it will register even $\frac{1}{700}$ second, which is a much smaller unit than is ever necessary.

Fig. 222 is a part of the time tracing from a chart made by the author. The breaks in the horizontal line occur once a second. This is the actual size of the tracing upon the chart. Signals occurring at a much more rapid rate would have to be registered on a sheet of paper moving at a much more rapid rate than in Fig. 222, where the paper moves only ½ inch a second.

Fig. 222.—Tracing made with Desprez signal. Each break equals one second.

Electrometric Charts.—Electric currents arising in the tissues spontaneously, or in consequence of artificial stimulation of some kind, may be registered upon a myographic chart, together with the other factors of the experiment. This is best done by having the moving strip of paper sensitized to light and inclosed in a camera, and casting an image of the capillary electrometer upon it. Variations in the height of the column of mercury are registered upon the chart. The details of the electrometric method are given on p. 318.

Myographic Charts.—Where several different factors are to be recorded, the most satisfactory way is to make the tracing upon a long strip of paper. But where the character of the muscular contraction alone is to be recorded and a comparison is desired between successive contractions, it is often desirable that the paper should be a short strip wrapped once around the revolving cylinder. A simple mechanism displaces the cylinder slightly after the completion of each revolution, so that the stilet when at rest traces a series of parallel horizontal lines. Another simple mechanism makes an electric contact at each revolution of the cylinder, but each time at a slightly later period. A convenient arrangement for accomplishing this is shown in Fig. 224. A cog-wheel with perhaps 100 teeth is fastened to the axis of the cylinder and causes the rotation of another wheel with 101 teeth. A projection at a certain part of the circumference of the latter produces an electric contact every time this wheel makes a complete revolution, and this takes a little longer than the wheel with a smaller number of teeth. The tracing in this case shows each muscular contraction separate and distinct, although the lines may cross each other as in Fig. 225.

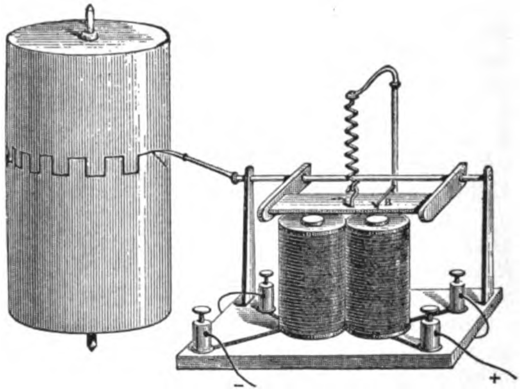

Fig. 223.—Desprez signal in operation.

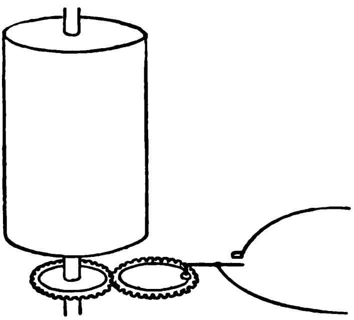

Fig. 224.—Mechanism for making an electric contact at a slightly later period of each revolution of the myograph.

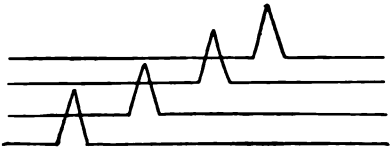

Fig. 225.—Successive muscular contractions excited and registered by the apparatus shown in Fig. 220.

Effect of Speed of Motion of the Paper Upon the Myographic Curve.—If the paper moves very slowly, each muscular contraction may be registered as a simple vertical line. The motion of the lever being rapid the up-and-down stroke may be complete before the paper has moved an appreciable distance. The tracing of a series of contractions under these circumstances looks like the teeth of a comb (Fig. 226). Such a tracing is valuable when only the height of several successive contractions is to be recorded, for instance, in studying the effect of fatigue upon muscular or nervous excitability. Fig. 227 is such a tracing showing fatigue from successive stimuli applied at intervals of two or three seconds, and registered upon a slowly revolving cylinder. The paper has moved only the distance between two successive lines during two or three seconds. It enables one to compare the height of a large number of contractions at a glance, but gives no idea at all as to the relative abruptness and other important features of the upward and downward strokes of the stilet.

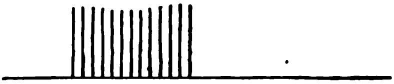

Fig. 226.—Comb-like tracing upon a slowly moving myograph.

Fig. 227.—Stair-case phenomenon from fatigue with periodic stimuli at intervals of two or three seconds and with slow rotation of cylinder (Weiss).

The cylinder revolves much more rapidly for this purpose, and the vertical motion of the stilet makes an oblique mark upon the paper. This line will usually be found to be curved, as in Fig. 228. If the paper moves at the same rate in a series of observations the abruptness of the upward and downward portions of the curve will vary with the abruptness of the muscular contraction and relaxation, and the entire length of the curve will vary with the time elapsing between the beginning and the end of the contraction. These features and the latent period or the length of time that elapses between the application of the stimulus and the beginning of the muscular contraction are among the chief indications furnished by the myograph.

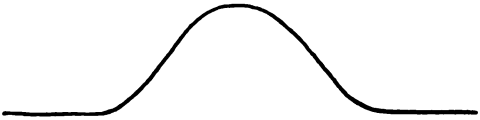

Fig. 228.—Tracing upon a rapidly revolving myograph.

Registering the Latent Period of Contraction.—Three different elements must be recorded: the units of time, generally indicated by a tuning-fork and Desprez signal; the closing of the electric circuit, also indicated by a Desprez signal; and the muscular contraction. In Fig. 229 the myographic tracing is represented as being made by the muscle (M) directly, though very often it is made through the intermediary of a pair of Marey's drums. The muscle is stimulated by a faradic current, and the primary current of the coil passes through a Desprez signal (S.S.), which records the turning on of the current. There is an entirely separate battery (B.2.) to actuate the tuning-fork and the Desprez signal (T.S.), which records the units of time—hundredths of a second usually. This arrangement shows the length of time that elapses between the application of the stimulus and the response of the muscle.

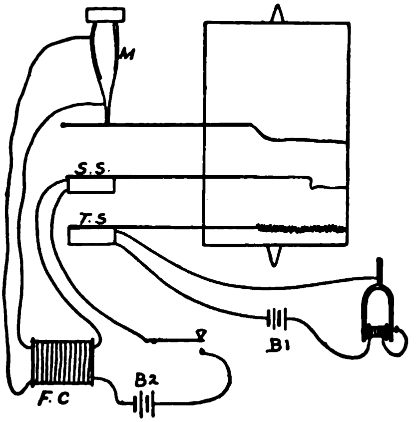

Fig. 229.—Measurement of the latent period of contraction. Myograph arranged to record units of time, the application of the faradic current, and muscular contraction.

A similar arrangement is employed for determining the latent period when the stimulus is applied to the nerve instead of the muscle.

Registering Muscular and Other Bio-electric Currents.—A pair of impolarizable electrodes (*E*, *E*, Fig. 230) are applied to the part to be tested, and are connected with the capillary electrometer *C*. An arc light of 500 candle-power and a suitable system of lenses and camera casts an image of the column of mercury through the slit, *S*. and makes a photographic record upon the sensitized paper as the registering cylinder revolves. All the other elements may be recorded upon the paper at the same time by suitable electric signals and Marey's drums.

The details of the arrangements required for this photographic record of bio-electric currents are shown in Fig. 230 from Tchiriev.[1]

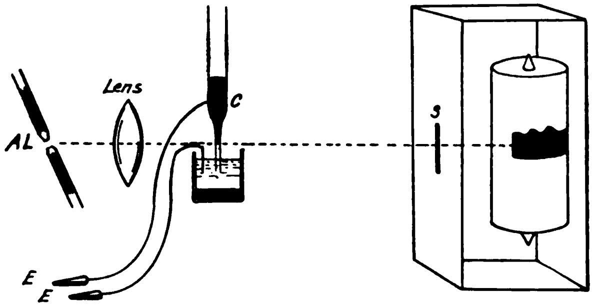

Fig. 230.—Apparatus for registering bio-electric currents with the capillary electrometer.

The apparatus employed includes a dark room, similar to the room used by photographers for making enlargements from ordinary photographs. It may be formed by placing a partition of compo-board across one corner of the laboratory. The arc light is inclosed in a lantern, and the capillary electrometer is placed between this and a projection microscope. The latter passes through a light-proof opening in the wall of the dark room, and forms the lens of a regular photographic camera with a bulb and shutter. The back of this camera is closed, except for a vertical slit which can be made wide or narrow. The vertical beam of light passing through this slit falls upon the sensitized paper. The cylinder makes a complete revolution in from two to

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[1] Journal de Physiologie et de Pathologie, vii, 1905, p. 597.

eighty seconds. The time units are registered either by a metronome, each ascent and descent indicating 0.375 second; by a tuning-fork indicating $\frac{1}{100}$ second; by an electromagnet making twenty vibrations a second, or by a Jacquet chronograph indicating one-fifth second.

In making such an observation a frog is narcotized or the brain is destroyed; it is carefully insulated by rubber tissue, and fastened upon Marey's myograph, and individual muscles are removed with the nerves still attached. The impolarizable electrodes from the capillary electrometer are applied, and if there is a current of rest, sometimes amounting to $\frac{1}{10}$ volt, this is counteracted by a battery and shunt circuit. Then the nerve is stimulated, and the muscular currents, or those that arise in the muscle in consequence of its contraction, are recorded photographically.

Burdon Sanderson[1] has done much valuable work upon the detection of electric currents due to the stimulation of muscles.

THE ELECTROCARDIOGRAPH

The Electrocardiograph.—When any muscle contracts, the active part becomes negative to other parts. Waller, in 1887, first demonstrated with a capillary electrometer currents due to cardiac activity and derived from electrodes applied to different parts of the surface of the body.

Electrodes in the form of bands of metallic gauze covered with woolen cloth may be wrapped around each hand, or a hand and a foot, or each foot, and when connected with a string electrometer will show electric currents which are synchronous with the action of the heart. The curve registered undergoes characteristic variations in different cardiac lesions, and this has become an important diagnostic aid in the hands of the heart specialist. The various positions of the electrodes give different normal curves.

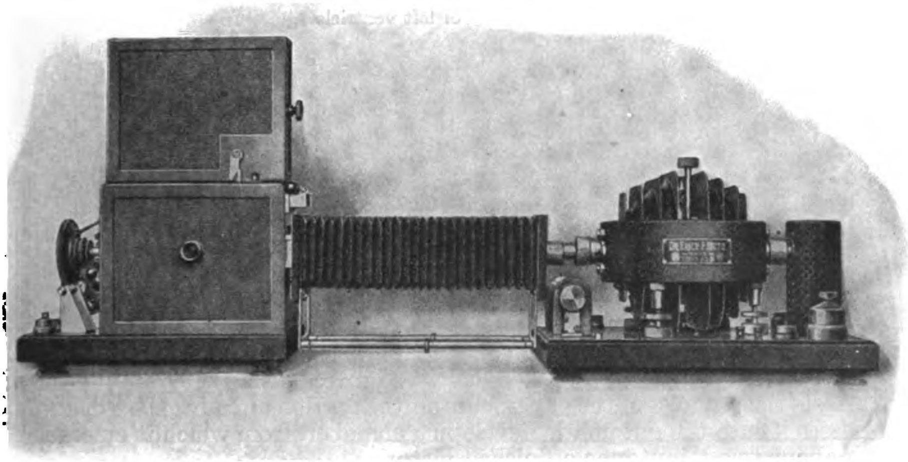

Fig. 231.—Electrocardiograph.

Einthoven's string electrometer (page 163) depends upon the deflection caused by the passage of these weak and transitory currents through a quartz filament tightly stretched in a powerful magnetic field.

Nicolai and Huth's portable electrocardiograph, (Fig. 231) is a de-

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[1] Journal of Physiology, 1895, vol. xviii, p. 128.

decided improvement. The string electrometer (page 163) consists of a platinum filament 4 inches long, with a resistance of 6000 ohms, stretched in the field of an electromagnet which weighs 60 pounds, and must be actuated by a direct current either from the electric-light circuit or from a storage battery. Other parts of the apparatus are an incandescent electric-light vacuum bulb, 4 cubic meters in diameter, in which there is a band of Wolfram or tungsten, 10 millimeters long and 1.5 millimeters wide, and through which passes a current of 7 amperes and 110 volts. The resulting light is as powerful as an arc lamp and has the advantage of requiring no adjustment.

The entire length of the string is not shown, only a portion at the middle, which is seen through a slit at a right angle with the length of the string. The image is projected by a Zeiss apochromatic 16 millimeter objective and No. 12 projection eye-piece, and a camera bellows excludes daylight. The registering apparatus is all enclosed, and contains a roll of bromide paper 60 meters long and 6 centimeters (2½ inches) wide, with an electric motor which draws a certain length of the photographic paper past the slit and registers tenths of a second upon it and numbers the strip.

A Marey's drum at the same time records the pulse or any other function desired. At the same time the record is being made the image is also visible upon a ground glass screen. Pressing a certain lever arrests the progress of the paper, cuts off the portion already exposed, and passes it into the automatic developing chamber, from which it emerges in about two minutes as a finished picture.

Hypertrophy of left ventricle.

Myocardiodegeneration.

Pericarditis with cardiac sufficiency.

Fig. 232.—Electrocardiograms from one hand to the other (after Boruttau).

The apparatus weighs about 125 pounds altogether, but is made up of separate parts which may be easily handled. It can all be placed upon a table 18 inches wide and 50 inches long.

The sensitiveness of the apparatus should be adjusted so that 1 centimeter equals 1 millivolt.

A standard voltaic cell and a rheostat are employed to neutralize the difference in potential or the skin current existing at the two places of contact. The resistance of the pair of electrodes is about 2.8 ohms, and the resistance of the patient is to be measured and is usually between 200 and 500 ohms. The most desirable leads or derivations are:

Lead I. Right Arm to Left Arm.
Lead II. Right Arm to Left Leg.
Lead III. Left Arm to Left Leg.

Phases of the Electrocardiogram.—Fig. 233, *P*, coincides with the auricular systole; *Q*, *R*, *S*, and *T* with stages of the ventricular systole, *R* and *T* being the most important in diagnosis and always present in health. The space between *P* and *Q* is the auriculoventricular interval, and shows the time required for the propagation of the impulse through the bundle of His. *Q* shows the ventricular contraction beginning at the base, and *R* the wave of contraction reaching the apex of the heart.

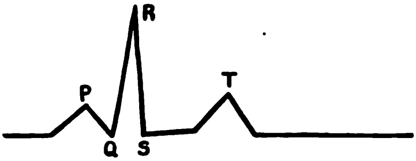

Fig. 233.—Phases of the electrocardiogram.

The ventricular curve gives an index to the functioning of the limbs of the auriculoventricular bundle, described by the Japanese physiologist, Tawara. Electrocardiograms are not directly affected by movements of the blood or the condition of the valves. They "purely express changes in the electric condition of the heart due to muscular activity."[1]

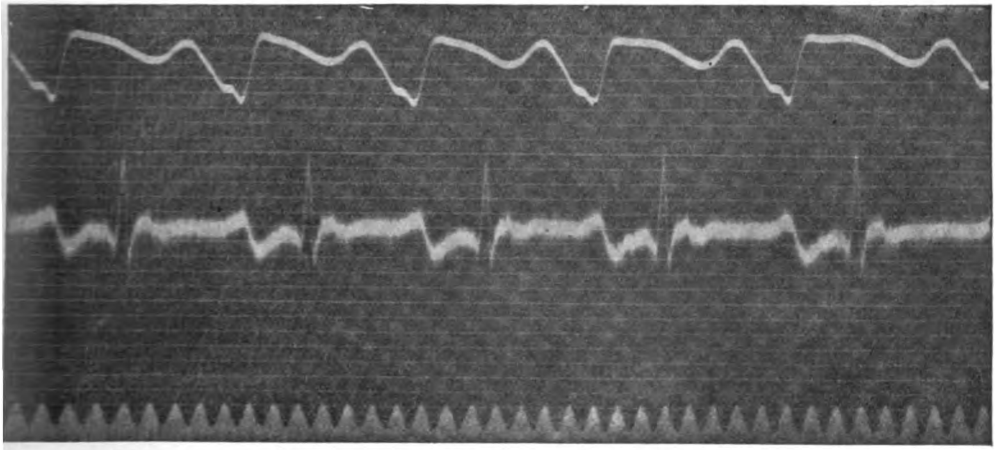

Fig. 234.—Electrocardiogram.

By some authors,

T is designated as F.
S as J.

Interpretation of Electrocardiograms.—*Hypertrophy of the right Ventricle.*—*R*, I (*i. e.*, *R* with lead No. I) is a very small upward projec-

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[1] Walter B. James and Horatio B. Williams, Amer. Jour. Med. Sci., Nov., 1910.

tion or may even be downward. *R*, III is upward and of greater magnitude than normally.

Hypertrophy of the Left Ventricle.—*R*, I is upward and of great height and *R*, III is downward to the extent of perhaps 2 millivolts.

Hypertrophy of the auricles may increase the height of *P*.

A negative after-variation or T is always abnormal and is often found in *arteriosclerosis*, in which disease it is an unfavorable sign.

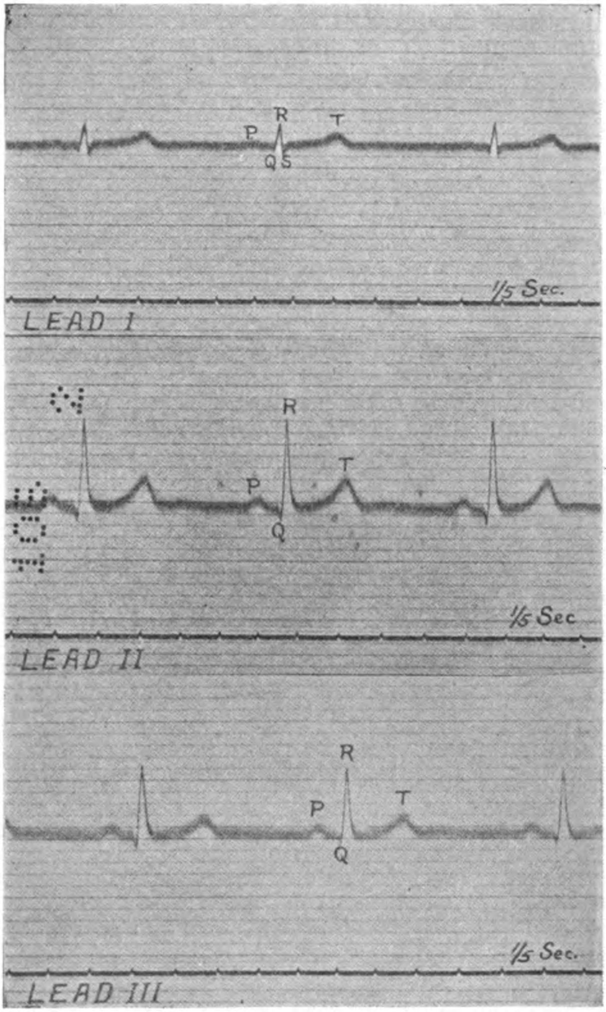

Fig. 235.—Electrocardiogram of a healthy adult male, taken while sleeping (James and Williams, in Amer. Jour. of Medical Sciences).

It calls for treatment by sinusoidal baths, and in one case, reported by Strubel, T became positive, and all the cases were benefited.

A distinct negative variation *S* of 0.1 to 1.25 millivolt is characteristic of *cardiac neuroses* and *neurasthenia*. It is of less frequent occurrence in *organic cardiac* or *vascular thyroid disease.*

An insufficient positive after-variation T in many *organic cardiac* or *arterial diseases* is improved by sinusoidal baths (Strubel).

Rapid pulse shortens the diastole represented by the distance between T and the following P, and is extreme when P and T coincide.

Irregularities of cardiac rhythm are clearly shown also extrasystoles and pulsus bigeminus. Ventricular extrasystoles sometimes give a high T wave followed by an S wave extending far below zero. Completely irregular heart, nodal rhythm, or pulsus irregularis perpetua show several small diastolic waves in each cycle without any normal P wave. This is thought to indicate that the trouble is due to *auricular fibrillation* (James and Williams).

In arterial hypertension and renal sclerosis the ventricular contraction is slow and jerky, and also in mitral stenosis. Functional trouble of the auricles and aortic insufficiency are clearly shown.[1]

Experimental section of one limb of Tawara[2] produces an enormous increase in ventricular, E. M. F., and an approach to a diphasic curve with a gallop rhythm. James and Williams give the electrocardiogram of a patient, with possible lesion of the right limb of Tawara. The patient has moderate hypertrophy, dyspnea increasing for the last five years, second aortic sound accentuated, no murmurs, but gallop rhythm.

H. Vaquez's investigations show no information as to the energy of the cardiac contractions.[3]

Experiments by R. H. Kahn[4] and by Eppinger and Rothberger[5] show that the currents produced by the two ventricles are in opposite directions; and Rothenberger and Winterberg show that these currents are not synchronous, and that the different phases shown in an electrocardiogram correspond to the contractions of the different portions of the heart.[6]

The heart-sounds and the electrocardiogram have been registered together by R. H. Kahn,[7] who finds that the first sound falls between R and T; the second sound begins $\frac{1}{500}$ second after the end of T.

Pachon's left lateral decubitus is desirable for electrocardiograms.

A. Lohmann and M. Rinck give practical directions for the use of the string galvanometer and photographic registration of the same.[8]

Dr. Walter B. James and Dr. Horatio B. Williams in this country have made important contributions to its clinical use.

Duhamel has invented an electrocardiograph provided with a dial and needle.[9]

Currents of Action in a Muscle During Tonic Contraction.—The current has about the strength of $\frac{1}{1000}$ Daniell cell, and the wave of negative variation has a speed of between 1 and 7 millimeters per second.[10]

Currents of Action in the Ureter.—Triple phase currents have been demonstrated, corresponding to the peristaltic waves in the ureter.[11]

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[1] R. Moulinier, C. R. Soc. de Biol., lxxi, 134, July 4, 1911.

[2] Eppinger and Rothberger, Zeithsch. f. klin. Med., lxx.

[3] C. R. de la Societe de Biol., lxxi, 28, July 1, 1911.

[4] Centralblatt für Physiologie, xxiv, 728, October 29, 1910.

[5] Ibid., 105-3, February 4, 1911.

[6] Ibid., 959, January 7, 1911.

[7] Archiv. für die ges. Physiologie, cxxxvii, 597, 1910.

[8] Archives für Physiologie, l, 447, 1910.

[9] C. R. de la Soc. de Biol., lxx, 106, January 21, 1911.

[10] Th. v. Brücke, Archiv. für die gesam. Physiol., 1910, cxxxiii, p. 313.

[11] L. Orbeli and Th. v. Brücke, Archiv. für die gesam. Physiol., 1910, cxxxiii, p. 344.

Currents Produced by Cold Applied to a Nerve.—The portion of a nerve which is cooled becomes positive to any other part.[1]

Contraction of the Separate Muscular Fibers.—This is a process of transverse thickening and of longitudinal shortening, and is probably connected with a chemic change in the protoplasm which is rapidly regenerated after the contraction has ceased.

Contraction of a Striated Muscle.—This occurs under the influence of an electric stimulus, usually as a shortening and swelling of the entire muscular mass, but sometimes as a wave of swelling advancing along the muscle, and sometimes as a swelling at one end of the muscle. The last-named condition may be produced experimentally at the beginning of a continuous current through the rectus abdominis muscle of a frog, dissected out and pinned to two corks. Impolarizable electrodes should be used. This muscle presents transverse tendinous septa, and at the beginning of the passage of a constant current, from one end of the muscle to the other, a swelling is seen at the cathode end of each muscular section (Fig. 236). A swelling is produced at the end where the current leaves each muscular section. It disappears, and a swelling occurs at the other end of each muscular section.

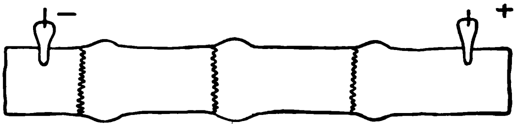

Fig. 236.—Stimulation of the rectus muscle of a frog. Swelling at the cathode extremity of each muscular section.

This is a simple example of a great law in regard to bipolar electric stimulation, viz.:

The wave of contraction in striated muscle arises at the cathode when the current is made, and at the anode when the current is broken.

Another example of the polar nature of muscular contraction is shown by means of Hering's double myograph (Fig. 237). The muscle is fastened at its middle point and the two electrodes are applied near the ends, the current is made, a contraction takes place in the half of the muscle to which the cathode is applied when the current is made, and in the portion to which the anode or positive electrode is applied when the current is broken.

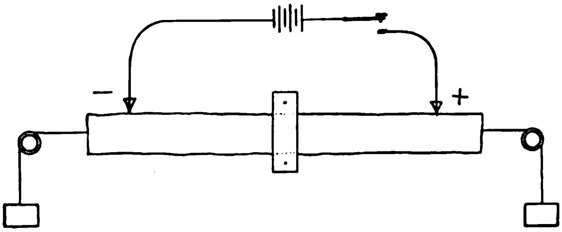

Fig. 237.—Hering's double myograph.

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[1] G. Galeotta and F. Porcelli, Recherche di elettro phisiol. secondo i criteri dell elettrochimica Zeit. für allegemeine Physiol., 1910, xi, p. 317.

F. W. Fröhlich[1] finds that when both electrodes are applied to one-half of a muscle which is fixed at its middle point, contraction takes place first in that half. It subsequently occurs in the other half. Contraction in the first half ceases, and the process of restitution begins while contraction is still present in the second half. This partly explains why the greatest muscular contraction is never obtained from a single stimulation.

The Refractory or Latent Period of Muscular Contraction.—A small period of time elapses between the application of the stimulus and the occurrence of muscular contraction. This occurs both when the stimulation is applied directly to the muscle and when it is applied to the nerve. In the former case it is about one-five-hundredth second. In the latter case there is added to this the time occupied in transmission through the nerve, and this averages about 30 meters a second.

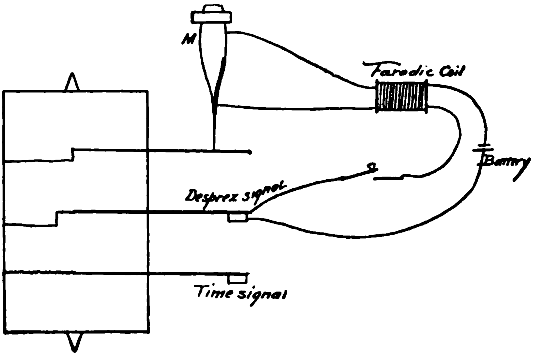

Fig. 238.—Latent period of contraction when the muscle is stimulated.

The latent period is measured by means of a myograph on which are recorded the units of time, the making of the current, and the occurrence of contraction when the electrodes are applied to the extremities of the muscle itself (Fig. 238).

The latent period in frog's muscles at ordinary temperatures is about one-two-hundredth second; it is shorter at high temperatures and longer at lower temperatures.

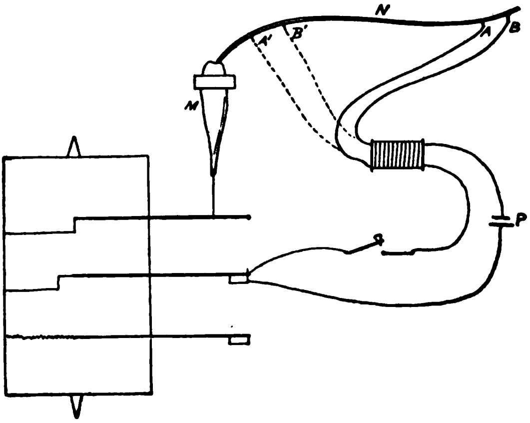

Fig. 239.—Time required for transmission by a nerve.

The time consumed in the transmission of the stimulation through a certain length of nerve is measured by the myograph, upon which

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[1] 16, 19, 67, May 6, 1905.

tracings of the units of time, the making of the current, and the occurrence of contraction in the same muscle when the electrodes are applied at two different parts of the motor nerves (Fig. 239) are recorded. Two separate measurements of the latent period are made, changing the position of the electrodes. The difference, in fractions of a second, between the two latent periods found in this way is due to the time consumed in transmitting the stimulation through the length of nerve between the two different parts at which the electrodes are applied. Human nerves transmit impulses at the rate of about 50 meters a second.

Bearing of the Latent Period of the Muscle and of the Nerve Upon the Effect of Alternating Currents.—Alternations more rapid than 50 to the second do not produce muscular contraction, because the effect of the current in one direction may not have time to develop before it is suppressed by the current in the opposite direction.

The Latent Period of the Spinal Cord.—By this is meant the time occupied by the cord in receiving an impulse from the stimulation of a sensory nerve, and in sending out an impulse through a motor nerve. It is the time required by the spinal cord for the performance of its reflex functions.

It is measured by means of the myograph. Electrodes from a faradic coil are applied to the motor nerve near the spinal cord and the latent period of contraction noted. The electrodes are then applied to the sensory nerve near the spinal cord, and the latent period of contraction is again measured. The increase in time required in the latter case is due to the latent period of the spinal cord (Fig. 240). The latent period of the cord is about twice as much as that of the whole length of the nerve.

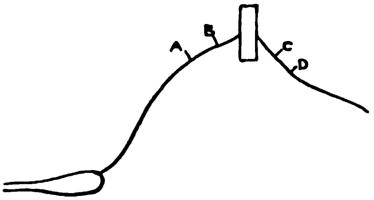

Fig. 240.—Latent period of the spinal cord.

The Muscular Wave.—A striated muscle whose nerve is stimulated either at some part of its course or at its insertion at the motor point of the muscle seemingly contracts simultaneously in all parts if it is in a normal condition. Certain diseased conditions, principally of the nerves, prevent this and cause the contraction to progress gradually from one part of the muscle to another. Poisoning by curare also produces this effect by paralyzing the motor plaques, the terminations of the nerve-fibers upon the individual muscular fibers.

But even under normal conditions a wave of contraction traverses the muscle after the application of a stimulus. This is associated with an electrometric wave. The wave of contraction is shown by means of a registering cylinder, one end of the lever resting upon the lateral surface of the muscle and being raised when the muscle swells and showing that the wave of contraction has reached that point.

It must be remembered that muscular contraction means shortening and broadening of the muscle—a change of form, not a change in volume, and that in polar stimulation with the anode there is a peripolar zone of contraction and a polar area of relaxation. There is quite the opposite with the cathode.

The wave of contraction arises at the negative electrode when the current quickly increases in strength, and at the positive electrode or anode when the current is broken or quickly diminished in strength.

Unstriated or **involuntary muscles** are commonly in a state of contraction and show a diminution of this tonic contraction at the anode when a constant current is turned on, and at the cathode when this current is broken. The muscles of the intestine are examples.

Differences in Electric Conditions Produce Differences in Muscular Contraction.—A continuous current turned on with gradually increasing strength must be made very strong to produce any contraction. A very weak current, if abruptly made and broken or changed in direction or changed in strength, will produce vigorous contraction. In some cases the direction of the current has an effect upon the contraction produced. Muscular contraction is produced by the variable period of an electric current, not by the constant period of the current, either maximum or minimum.

Monopolar stimulation is effected by placing one electrode upon the muscle or nerve while the other is applied to some indifferent part of the animal at a distance from the first. The diffusion of the current in the immediate neighborhood of the active electrode takes place about equally in all directions. There is neither an ascending nor a descending current in the nerve or muscle. A muscle responds about equally well to positive or negative monopolar stimulation, but a nerve or the motor point of a muscle shows a marked difference between negative and positive monopolar stimulation.

Contractions Occurring at the Making or Breaking, Closure or Opening, of the Constant Current.—There is an anodal opening contraction when the current is broken while the anode is upon the muscle or nerve and the cathode is upon some indifferent part of the body. The other designations are cathodal opening contraction, anodal closure contraction, and anodal opening contraction. The names indicate the active electrode, or the one which is applied to the muscle or nerve, and whether the circuit is closed or opened.

NORMAL ELECTRIC REACTIONS AND DESIGNATIONS OF THESE CONTRACTIONS

English.	French.	German.
Cathodal or kathodal closure contraction CaCC or KCC.	(Closure..fermature; contraction..secousse) Ca FS or KFS.	(Closure..Schliessung; contraction..Zuckung) KSZ.
Anodal opening contraction AOC.	Opening..ouverture AOS.	Opening..Öffnung AÖZ.
Anodal closing contraction ACC.	AFS.	ASZ.
Cathodal or kathodal closure tetanus CaCT or KCT.	CaFT or KFT.	KST.
Cathodal or kathodal opening contraction CaOC or KOC.	CaOS or KOS.	KOZ.

AOC and ACC are not far from equal, and the latter is given as the greater in many tables of this kind. CaCC is much stronger and CaOC much weaker.

REACTIONS TO ELECTRIC STIMULATION IN NEUROMUSCULAR PREPARATIONS

A battery of variable strength may be used. The variations may be secured by changing the number of cells employed or by using a rheostat or a volt controller. One hundred and ten volts direct electric-light current may be modified by rheostats and volt controllers so as to serve the same purpose. Having made the proper connections by means of suitable electrodes, a very weak current is turned on, and then, after flowing continuously for several seconds, it is turned off. A convenient way of closing and opening the circuit is by means of a Morse telegraphic key. With the weakest currents no muscular contraction occurs at any time. As the strength of the current is gradually increased, muscular contractions begin to take place. One notes the strength of the current required to produce contraction when the electrodes are variously placed and when the current is made or broken. Normally, the weakest current that will produce a muscular contraction at the closure or turning on of the circuit with the cathode as the active electrode applied to the nerve will not produce any contraction with the cathode when the current is opened or broken, or with the anode when the circuit is either opened or closed. And with neither the cathode or the anode as the active electrode will there be any contraction during the flow of the current.

The first change that is noted as the current is increased is that the cathodal closure contraction increases in strength, and that anodal opening contraction occurs.

It requires a still stronger current to excite anodal closure contraction. And with an extremely strong current cathodal closure tetanus occurs. This is a continued contraction following the closure of the circuit, and lasting an appreciable length of time. The other contractions mentioned have been apparently instantaneous shortening, immediately followed by relaxation.

The effect of the strongest current suited for such experiments is to produce cathodal opening contraction.

"CaCC 5 milliamperes" is an abbreviation for the statement that cathodal closure contraction requires a current of at least 5 milliamperes.

Form of the Myographic Tracing.—Each muscular contraction shows three phases in the myographic tracing: They are a refractory or latent period, a period of ascent, and one of descent. The curve representing the period of descent is usually longer and less abrupt than that of ascent.

The form of the curve varies in different animals and in the same muscles in the same animal. It varies under the influence of fatigue, heat and cold, and other agencies.

The Effect of Temperature.—Changes in temperature act in a very marked manner. Fig. 241 shows the maximum height of the myographic curve at different temperatures from 0° to 38° C., according to the observations of G. Weiss. The weight to be lifted remained the same, and the same electric stimulation was applied with a long enough interval to avoid the influence of fatigue. The effect of increasing the temperature is to render the contraction very much shorter in duration. A study of this and other charts shows that between −5° and 0° C. (the freezing-point of water) an increase of temperature produces an increase in the height of contraction. At −5° no contraction occurs, and at 0° C. a

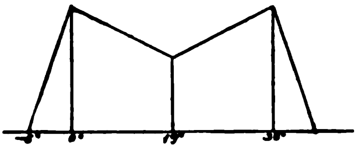

Fig. 241.—Height of the contraction at different temperatures C. (isotonic) (Weiss).

maximum contraction occurs. From 0° to 19° C. the height of contraction diminishes slightly, and from 19° to 38° C. (the temperature of the human body) it rises again to the same maximum. Raising the temperature beyond 38° C. the muscular contractility is seen to fall very rapidly and completely disappear; and at the same time the muscle ceases to return to its original length after each contraction, but tends to pass into a state of persistent contracture. The latter condition may be permanent if the muscle is not cooled quite promptly.

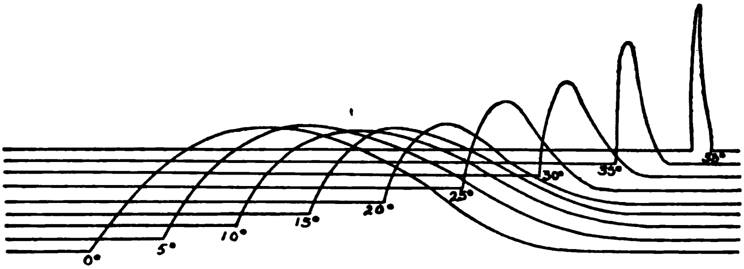

Fig. 242.—Wave of contraction at different temperatures C. (isotonic) (Weiss).

Fig. 242 from G. Weiss shows the comparative height of muscular contraction following equal electric stimuli, but at different temperatures.

The effect of temperature upon the response of muscle to electric stimulation is modified by the rapidity and direction of the changes of temperature and by the conditions under which the muscular work is accomplished. This is true both of single muscular contractions and of experimental tetanus.[1]

Influence of Fatigue.—Z. Treves[2] has made experiments which go to show that the progressive diminution in the amount of work performed in a unit of time by a muscle under electric stimulation of its nerve is due more to nervous than to muscular fatigue.

Influence of Resistance.—The greatest height of contraction is produced when a suitable small resistance is to be overcome, such as a small weight to be lifted. Electric stimulation produces contraction when there is no weight to be lifted or when the weight is increased within certain limits, which are sometimes quite extensive. A heavy weight prolongs the period of ascent and shortens that of descent, and with a very light weight the period of descent may be very long.

Extensibility.—The extensibility of a paralyzed muscle is independent of its electric excitability. E. Overton has shown that removal of all the sodium chlorid in the muscular substance renders it completely inexcitable. Motonosuke Goto[3] has studied the extensibility of muscles paralyzed in this and other ways, and finds it unaffected.

Effect Upon Resistance to Rupture.—The resistance of a muscle to rupture during contraction from electrization is equal to the sum of the breaking strain of the muscle when at rest, and the force of its contraction when stimulated.[4]

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[1] J. Carvallo and G. Weiss, C. R. Soc. de Biol., eleventh series, 1, 660, July 15, 1899, and 686, July 22. 1899.

[2] Archiv. di Fisiologia, 2, 237, 1905.

[3] Zeit. f. Biol., 46, 39, 1904.

[4] J. Carvallo and G. Weiss, C. R. Soc. de Biol., tenth series, 6, 122, February 18, 1899.

Wave of Muscular Contraction.—A muscle stimulated at any one point usually contracts in every part, but this contraction may not take place everywhere simultaneously. Aeby has placed two myographic levers at different parts of a long muscle and has sometimes seen the levers move at different times, indicating the progress of the transverse swelling and longitudinal shortening, which is called the wave of muscular contraction.

Single muscular fibers observed under the microscope show a progressive wave of transverse swelling under the stimulus of an electric current (Fig. 243).

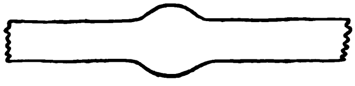

Fig. 243.—Wave of contraction in a single muscular fiber.

Stimulation of the nerve does not cause a wave of muscular contraction. All parts of the muscle contract at once. The same is true of stimulation at the motor point of the muscle, since this is really stimulation through the nerve at its place of subdivision. Stimulation of a muscle at the point farthest from the entrance of the nerve may cause a wave of contraction; and stimulation of a curarized nerve always does. The wave of contraction in living human muscle travels at the rate of about 10 to 13 meters a second.

DuBois-Reymond's Law.—DuBois-Reymond's law is that the muscular contraction is influenced by the magnitude and suddenness of the change in the strength of the current. Many circumstances modify this and make the mathematic application different in the various forms under which the current is applied, such as condenser discharges, induced currents, and interrupted galvanic currents. Different formulas have been found by various observers to correspond closely with the results of their experiments under these different conditions. No one simple formula suffices even approximately for every condition.

Nature of Nervous and Muscular Excitability.—The stimulating effect of electricity upon a nerve or a muscle is doubtless due to a change produced in the tissue, and this is supposed to be of the character covered by the term electrolytic used in its broadest sense. There is a migration of ions and a difference in the osmotic pressure inside the muscular cells and the nerve-fibers. Chemic stimuli produce their effect in a similar manner.

The electrolytic effect upon muscle is shown by the demonstration of a current of polarization after the application has ceased, and even interstitial changes may be visible to the microscope.

Stimulation of nerve-fiber under ultra-microscopic examination produces a current of action, but no visible change in the colloid appearance.[1]

The ionization of the salts in different animal cells when it reaches a certain degree affects the albuminoids sufficiently to produce a stimulation (threshold of stimulation) in nerve or muscle. Nernst's theory is that those tissues may be considered a series of cells separated by semipermeable membrane.[2]

The **osmotic pressure** in muscles is raised sometimes as much as 2.6 kilograms per square centimeter when the muscle is in a state of contraction.[3] The elevation is greatest when the stimulation is pro-

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[1] R. Höber, Archiv. f. die gesam. Physiologie, cxxxiii, 254, 1910.

[2] P. Lasareff, Archiv. für die ges. Physiologie, cxxxv, 196, 1910.

[3] Stephane Leduc, Bulletin Medical, 140, 1190, May 1, 1905.

longed and strong. It is, perhaps, the chief factor in the development of fatigue.

Application of Electric Stimulation.—The stimulation may be applied indirectly through the intermediary of the nerve or directly to the muscle itself. In the latter case the result is due partly to electric stimulation of the muscular fibers, but largely to stimulation of the peripheral terminations of the nerve-fibers. The effect of the latter may be eliminated by the administration of curarin, an alkaloid which paralyzes these motor plaques.

Stimulation of a Muscle or Nerve through the Unbroken Skin (Monopolar Stimulation).—A small electrode is applied to the surface of the body over the course of the nerve or over the muscle, and another electrode, which may be larger, is applied at some distant indifferent part. The influence of the current at the active electrode is greatest near this electrode, and becomes weaker as the lines of force spread out in every direction through the body. This creates a difference in the nerve or muscle by an electrolytic action, and under certain conditions demonstrable contraction is excited.

Points of Election or Motor Points.—These are the places upon the surface of the body where the application of the active electrode results in the strongest muscular contraction. The motor point of a muscle generally corresponds with the point at which the motor nerve enters it, and divides into its terminal ramifications. Stimulation at the motor point is really stimulation of the motor nerve, but limited to the individual muscle. If the active electrode is small, the current of moderate strength, and the motor point accurately found, the individual muscle may be made to contract, while the neighboring muscles remain relaxed. This is one basis of the use of electricity in diagnosis and treatment.

Charts of the Motor Points.—These are more or less diagrammatic pictures of different parts of the body, showing the motor points according to Erb's classic observations. They are of service as a general guide, but the exact localization is partly a matter of experiment in each case.

Degree of Excitability to Percutaneous Stimulation.—The normal degree of sensitiveness of the muscle or nerve to the make or break of the current is the same as that given on p. 327 in describing the effect upon exposed nerves or muscles.

The Strength or Height of Contraction.—The strength of contraction under the different conditions of polarity and opening or closure of the circuit follows the order of their appearance as given in the table (p. 327). The cathodal closure contraction is normally the strongest of all.

Minimal and Maximal Contractions.—Taking any individual phase, such as the cathodal closure contraction, and tracing its magnitude by means of the myograph, we find that a weak current produces no contraction at all; that the weakest current that will excite any contraction at all produces a minimal contraction, and that as the current is increased in strength a maximal contraction is obtained, which is not surpassed by further increasing the strength of the current.

The production of the minimal contraction is called by the French the threshold of contraction.

Some muscles do not contract at all unless a current strong enough to produce a maximal contraction is applied. The cardiac muscle is an example, and if the auricle of a frog's heart is completely separated, it soon ceases to beat spontaneously, but may be stimulated to contract by an electric current; but only the maximal contraction is known.

The **effect of a series** of stimuli in rapid succession is to progressively increase the height of contraction. There is a limit, however, which is reached in a very short time, and then the effect of fatigue becomes apparent in a diminished height of contraction.

It is the same in regard to the maximal contraction. The greatest height of contraction that can be produced by a single stimulus is exceeded if successive stimuli of the strength required to produce a maximal contraction are applied. Fig. 244 is a myographic tracing made with a slowly revolving cylinder, and stimuli applied at such short intervals that we get the effect of an increase above the maximal contraction from a single stimulus. The stimuli applied are all equal, but the height of contraction increases progressively up to a certain limit and then diminishes to a certain limit in consequence of fatigue. Fig. 245 is a tracing upon a rapidly revolving cylinder.

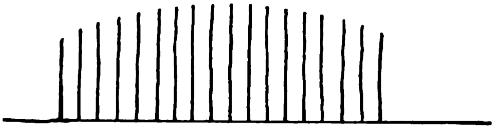

Fig. 244.—Tracing on a slowly revolving cylinder and with stimuli applied at short intervals. Increase in maximal contraction followed by fatigue.

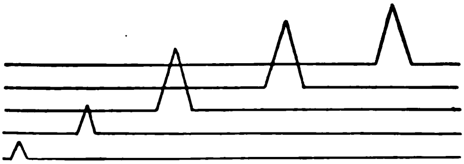

Fig. 245.—Myograph showing increasing height of muscular contraction with increasing strength of current. Each contraction is measured from its own horizontal line. The maximum contraction is reached in this diagram at the third stimulation. Although the strength of current is still further increased, the stimuli are applied at long intervals and we, therefore, do not get the effect of a rapid series of stimuli which would increase the maximal contraction.

Electric Muscular Tetanus.—If stimuli are applied in such rapid succession that one contraction has not ceased before the next contraction begins, we have the condition of continued contraction which is called tetanus. This condition does not imply the presence of the dangerous infective disease called tetanus, although it occurs as one of the symptoms of that disease. The apparently continuous contraction of the muscles of the forearm which takes place physiologically when we grasp anything firmly is not exactly analogous to the tetanus produced by very rapidly repeated electric stimuli. The muscular cramp which is so dangerous when it attacks one in swimming is more closely parallel, though electric tetanus is not painful unless a powerful current is applied.

Faradization affords a familiar example of electric tetanus, but the latter is not necessarily a phenomenon of high tension or of induced currents. It is due, on the other hand, to the rapidity of the stimuli, and a sufficiently rapid series or alternations will produce tetanus with very weak currents.

The height of the continued contraction in electric tetanus is much greater than the maximal contraction from the strongest single stimulation (Fig. 246).

Fig. 246.—Height of contraction in electric tetanus exceeds the maximum from a single stimulation.

Not only is the contraction produced by periodic stimuli stronger than that from a single stimulus, but it is more easily excited. Periodic stimulation of the exposed sciatic nerve in a frog will excite reflex contraction of the muscles of the opposite limb, while the strongest single stimulation will not do so.

The Production of Electric Tetanus.—J. Carvallo and G. Weiss[1] believe that the magnitude of the successive stimuli is of greater importance in the production of tetanus than their frequency, and that its determination is easier. Both factors are essential, however, in the case of a unidirectional current, as well as in the case of the periodic (alternating) currents from an induction coil.

Submaximal Tetanus of Striated Muscles.—A striated muscle undergoes a series of uniform contractions when it is subjected to a series of maximal stimulations. A. Samojloff[2] finds that less powerful electric stimuli produce a series of unequal contractions, and that the inequality does not follow any definite law.

Maximal and Submaximal Contraction.—The greatest amount of muscular contraction which can be caused by a single electric stimulus is called *maximal muscular contraction.*

Any smaller amount of muscular contraction is known as *submaximal muscular contraction.* A maximal stimulation is produced by an electric stimulus powerful enough to produce maximal contraction.

A series of maximal stimuli from an induction coil produces a tetanic contraction whose myographic tracing is a regular curve; but when weaker induced currents are used, the tetanic contraction makes an irregular and trembling trace. Cooling a muscle causes the tetanus to become regular.

A. Basler[3] has shown that the sartorius muscle of a frog is easily put into submaximal tetanus by weak faradization of its nerve, while a much more slowly interrupted or alternated current will produce tetanus only with a current which is strong enough to produce a maximal contraction. Submaximal contraction becomes a continuous tetanic contraction if the stimuli occur as rapidly as 27 times a second, while maximal contractions do not become continuous unless the stimuli are as frequent as 34 a second. The myographic chart made with between 27 and 34 interruptions a second shows a continuous fused tetanus with weak currents, and a serrated tetanus with strong currents. Basler explains this on the theory that the weaker current stimulates only the thin, slow, easily excited muscular fibers, while stronger currents stimulate the rapid fibers which are more difficult to excite. The frog's gastrocnemius muscle does not answer for this experiment.

The effect of alternating or of interrupted direct currents is to produce exactly the same muscular tetanus, provided the successive alternating

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[1] Journal de Physiologie et de Pathologie, 1, 1899, 443.

[2] Arch. f. Physiol., 512, 1899.

[3] Arch. f. d. ges. Physiologie, 105, 344, 1904.

currents are exactly similar except as to direction. Carvallo and Weiss[1] have tested this fact by means of a dynamo of special construction, giving uniform periodic currents, either direct or alternating.

Tripolar Stimulation.—This consists in the application of a single electrode from one pole of the battery, and of a forked electrode or two electrodes from the other pole. The single electrode is applied between the other two. In such a case the forked electrode is the more active, and it will, for instance, prevent the occurrence of electrotonus due to the middle electrode when the application is made to an exposed nerve (Fig. 247).

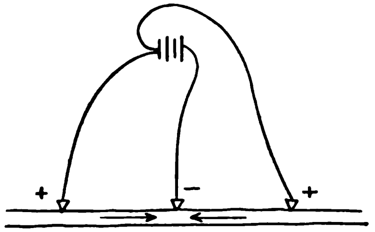

Fig. 247.—Tripolar stimulation.

It affords a means of producing an effect upon a deep-seated nerve without diffusion of the current. Setschenow, in 1895, and B. Werigo[2] have especially investigated the effect of tripolar stimulation.

Peripolar Stimulation.—This occurs when a small electrode is applied over the middle of a nerve or muscle in an uninjured limb, and a large electrode is applied to the opposite side of the limb. In Fig. 248 the negative electrode is over the muscle. The direction of the current through the muscle is from both ends toward the center. Of course, all the current from the large indifferent positive electrode does not go to the two ends of the muscle, as the diagram would indicate, but really spreads out from the anode and, entering the nerve or muscle at many different points, it passes along the muscle, to leave it chiefly at a point as near as possible to the cathode.

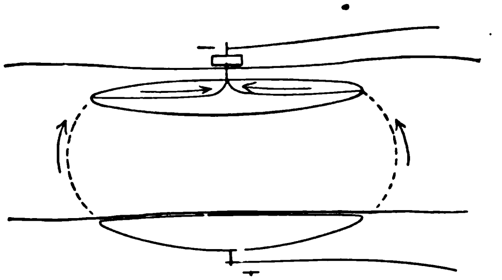

Fig. 248.—Peripolar stimulation.

There is thus produced in the nerve or muscle the same tripolar stimulation as if the nerve or muscle had been exposed, and a single negative electrode had been applied between two electrodes from the positive pole of the battery.

Virtual or Physiologic Electrodes.—The electric current passing through the muscle from either end toward the center may be regarded as passing from a positive physiologic electrode at either extremity to a negative physiologic electrode at the center. The names virtual or physiologic electrodes indicate the place at which the current enters

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[1] Journal de Physiol. et de Pathol., 1899.

[2] Arch. f. d. ges. Physiol., lxxvi, 517, 1899.

and leaves the muscle after having passed through the different structures of the limb from the places where the real electrodes are applied. The real electrodes are the metallic or other terminals from the two poles of the battery.

It has already been stated that the single middle electrode in tripolar stimulation is deprived of much of its effect, and that the outer forked electrode is the active one. This condition prevails to a certain extent in peripolar stimulation and may explain the phenomenon of the reaction of degeneration.

Nature of the Electric Current Employed.—Variations in the strength of a galvanic current produce muscular contraction the height of which increases with the amount and abruptness of the change in the strength of the current.

Induced currents provoke contraction and are very readily applied, either as isolated induction shocks or as the periodic discharge from a faradic coil.

Faradic excitability may be lost and galvanic excitability retained in certain diseased conditions, or the reverse may be true. These deviations from the normal yield important information as to the condition of the nervous and muscular systems, and furnish indications for the proper electrotherapeutic application.

The primary current of a faradic coil is an interrupted galvanic current with a high-tension element due chiefly to the self-induction occurring each time the current is broken. This form of current may be used to excite muscular contraction.

Von Helmholtz's faradic coil has the connections of the primary coil so arranged that there is never a complete break in the primary circuit. At a certain stage the current passes through the primary coil in full force, and at another stage a large part of the current is diverted through a shunt of low resistance. The object of this is to eliminate the self-induction occurring in the primary coil when the current is completely broken, and make the variations in strength of the primary current equal. The reduction and increase in the primary current being of the same quantity and abruptness, the currents induced in the secondary coil at these two phases of the primary current are equal. A faradic current from such a coil does not have the polarity which characterizes that from an ordinary faradic coil. There is no difference in the effect upon muscles or nerves whichever is the active electrode, while with the ordinary faradic coil the currents in one direction are much stronger than those in the other.

CORTICAL STIMULATION

Epileptiform Convulsions Produced by Cortical Stimulation.—Stephane Leduc[1] shows that intermittent currents of low tension applied directly to the cortex of the brain will produce the group of symptoms typic of epilepsy. He thinks it practicable to study the effect of different therapeutic measures upon this artificially induced epilepsy.

J. L. Prévost and J. Mioni[2] have studied the effect of thyroidectomy upon the epilepsy induced in young animals by alternating currents. They find that it prolongs the stage during which cortical stimulation

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[1] Arch. de med. des. Infants, 12, 771, October 25, 1904.

[2] C. R. de Soc. de Biol., 58, 69, January 14, 1905.

produces tonic convulsions without clonic convulsions. The administration of thyroid extract, on the contrary, causes clonic convulsions to follow cortical stimulation.

Perspiration from Stimulation of a Center in the Cortex of the Brain.—A. G. Grieboiedoff[1] made 30 or 40 experiments upon kittens, trephining the skull and faradizing the cerebral cortex. In 4 cases he found a center in the upper part of the gyrus antecruciatus, where stimulation was followed by more or less profuse perspiration of the opposite side of the body, lasting five or ten minutes.

The same result was obtained in a colt by stimulating a center about the size of a silver 10-cent piece in front of the motor area. Ligature of the blood-vessels of a limb did not prevent sweating when the cerebral center was stimulated. Neither did the use of curare prevent muscular contraction.

Movements of the Muscles of the Eye from Stimulation of the Cortex of the Brain.—R. duBois-Reymond and P. Silex[2] have studied this subject, and find that in dogs there are three different centers where electric stimulation produces movement of the eye. One is the visual sphere, another is a point in the center for movements of the neck, and another is in the center for movements of the face. Stimulation of the first two produce associated movements. Stimulation of the last-named produces isolated movements. The visual sphere has to do only with movements which normally accompany the exercise of the visual function.

STIMULATION OF THE CEREBELLAR PEDUNCLES

F. H. Thielle[3] finds that this produces movement principally of the muscles on the same side of the body.

Cerebellar Localization by Electric Stimulation.—G. Pagano[4] finds that there are two special areas, one for the upper extremity on the same side, and the other for the posterior extremity on the same side. The first of these is located at the middle and lateral part of the vermis; the other, a little back, on the base of the lateral lobe near the vermis. Stimulation of these areas does not produce spasmodic movements, but attitudes maintained by a muscular contracture. The posture may be one of flexion or extension, adduction or abduction, and so many muscles may be involved as to indicate that many centers are grouped in a very small area. These centers are at some little depth. The contracture may be modified by the will. Another feature of stimulation of the anterior extremity of the vermis is exaltation with anxiety and terror, but no forced or ataxic movements, although it does cause a violent reaction to noises or other slight external causes. With this psychic exaltation there is vertigo, and the dog upon whom the experiment is tried barks and whines. From this experiment it would appear that the anterior part of the vermis normally plays an important rôle in the different emotions and in their expression.

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[1] Vratch. gaz. Ancien. Ejendelnik, October 9, 1904, 1186.

[2] Journal de Physiol. et de Pathol., 1899.

[3] Jour. of Physiol., 32, 359, 1905.

[4] Arch. Ital. di Biol., 43, 139, 1905.

ELECTRIC STIMULATION OF THE SPINAL CORD

V. Decceshi[1] stimulated the spinal cord of a frog by means of shocks from an induction coil, and measured the contraction of the gastrocnemius muscle. The latter was much reduced if a weak solution of sodium chlorid was caused to circulate through the blood-vessels of the spinal cord. This reduction took place with hypotonic solutions, or those of a strength less than the normal $\frac{6}{10}$ of 1 per cent. contained in the blood. A greater strength of salt solution caused an increase in electric excitability, which may even amount to tetanus, and the animal may even die from exhaustion. These effects may be due to the physical effect of dehydration of the nervous tissues by hypertonic salt solution and imbibition caused by hypotonic solutions.

J. Joteyko's experiments[2] upon the fatigue of the nervous centers by electric stimulation show that the centers in the spinal cord are at least twice as resistant as the peripheral terminations of the nerves.

S. Baglioni[3] shows the importance of the presence of oxygen to the functions of the spinal cord. The isolated spinal cord of a frog loses its excitability in an hour. But this persists for twenty-four or thirty-six hours in a gaseous or liquid medium rich in oxygen, such as oxygen gas under pressure or water through which a current of oxygen is passing, or a solution of H_2O_2.

The Excitability of the Spinal Cord.—The excitability of the spinal cord adapts itself to the intensity and periodicity of the stimulation. G. and A. Pari[4] find that reflexes excited by the stimulation of a centripetal nerve are usually equal if the stimuli are equal. If, now, the stimuli are markedly changed in strength, there is at first a corresponding change in the reflex effect, but later the latter returns to the original strength. The spinal cord as a reflex motor center adapts itself to the strength of the stimulation applied, and after this adaptation has taken place the same reflex effect is produced by a weak as at another time by a strong stimulus. And the minimum stimulation which will produce a reflex effect depends upon the strength of the stimulus to which the cord has previously been subjected.

A. Pari[5] has found that the automatic oscillations of excitability in the centers in the cord have a tendency to synchronize themselves with the rhythm of a periodic stimulation. Rhythmic stimulation of the nerve-centers causes a rhythmic muscular contraction, but the latter is of an oscillating amplitude; strong contractions alternate with weaker ones. This is due to physiologic alternations in assimilation causing rhythmic alternations in excitability, and if these are not of the same rapidity as the rhythmic current, they spontaneously become so.

Uterine Contraction from Stimulation of the Spinal Cord.—E. Chidishimo[6] finds that electric stimulation of the spinal cord below the origin of the tenth dorsal nerves causes the movements of the uterus to become regular and more energetic whether they are excited directly or reflexly.

He has sought in vain to find a center in the cortex of the brain

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[1] Lo Sperimentale, 52, 283, 1898.

[2] C. R. Soc. de Biol., eleventh series, 1, 384, May 20, 1899.

[3] Arch. Ital. di Biol., 42, 83, 1904.

[4] Zeit. für allg. Physiol., 4, 215, 1904.

[5] Arch. Ital. di Biol., 42, 217, 1904.

[6] Ibid., 42, 323, 1904.

where stimulation will cause uterine contraction. Stimulation of the dura mater, however, reënforces uterine contractions.

He has found no such center in the medulla.

Loss of Excitability in the Spinal Cord in a State of Degeneration.—Destruction of the motor area in the brain is followed within eight days by complete loss of faradic excitability from stimulation of the internal capsule or of the peduncles of the brain. (Vera Norowska Oscherowitsch, experiments upon dogs.[1])

Variations in the Excitability of Motor Nerves.—Nerve-fibers undergo changes in excitability when various salts are applied to them, and this change is associated with modifications of structure and colorability.

Effect of Carbonic Acid.—Waller[2] concludes from his experiments that electric reactions in a nerve are increased by small and diminished by large quantities of carbonic acid.

Yohimbin and protoveratrin have many physiologic effects in common, but yohimbin prolongs the refractory phase while protoveratrin increases the electric variation of a nerve which is stimulated. Studies with these two substances lead J. Tait[3] to conclude that the refractory period corresponds with the period of electric variation.

Poisoning by oxalic acid destroys the faradic excitability of the vagus nerve in warm-blooded animals.[4]

Loss of Nervous Conductibility from Narcotics.—General anesthesia from ether, chloroform, morphin, chloral, alcohol, or other drugs reduces the conducting power of the nerves and may completely abolish it. The latter takes place abruptly, having been preceded by a certain stage at which the nerve is easily fatigued by strong and frequent induced currents. The same changes take place when the narcotic is applied directly to the nerve, but F. W. Fröhlich and J. Tait[5] find that, owing to its abundant vascularity, the intact nerve is very resistant to such influences.

Local inexcitability is apparently more easy to produce by the topical application of a narcotic than loss of conductibility.

Narcosis always increases the latent or refractory period intervening between the application of a stimulus and the resulting muscular contraction.

In animals poisoned by curare, nicotin or ether fatigue from repeated electric stimulation attacks chiefly the peripheral terminations of the nerves, while in normal animals it is chiefly the muscular fiber itself.

Cocain has a selective action upon the different fibers of a mixed nerve. The sensory filaments are paralyzed before the motor; the descending fibers of the pneumogastric before the ascending; vasoconstrictors before vasodilators, and bronchoconstrictors before bronchodilators. The effect is upon the nerve-fibers, and not like that of curare upon the end-plates of the nerve.[6]

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[1] L'excitabilité electrique des voies nerveuses centrales en dégénerèscence, Centralblatt für Physiol., xxiv, p. 393, July 23, 1910.

[2] Centralblatt f. Physiol., 12, 745, February 4, 1899.

[3] Quarterly Journal of Experimental Physiology, iii, 221, 1910.

[4] R. Chiari and A. Fröhlich, Archiv. für experimentalle Pathologie and Pharmakologie, lxvi, 110, 1911.

[5] Journal de Physiol. et de Path., 1905.

[6] Dixon, Jour. of Physiology, 1904, 32, 86.

Influence of Fatigue on Electric Excitability.—J. Joteyko's experiments upon the fatigue of the nerve terminations[1] show that these are much more rapidly fatigued than the muscles when an induced current is used.

Influence of Circulation Upon Nervous Exhaustion.—K. Taskinen[2] shows by experiments upon frogs that while a muscle with circulation regains its excitability in three to six hours after complete exhaustion, a muscle without circulation, but in an atmosphere of oxygen, regains its excitability only partially. A rapid rhythm exhausts a muscle with circulation sooner than one without circulation. A slower rhythm than once every four or five seconds is more favorable to the muscle with circulation.

Influence of Traction Upon Nervous Excitability.—The electric excitability of a nerve is diminished by traction upon it, differing in this respect from muscular excitability.[3]

Electric Response of the Nerve to Two Successive Stimuli.—Francis Gotch and J. Burch[4] have made electrometric measurements of a nerve subjected to rapidly repeated stimuli. The nerve does not give an electric response to a second stimulus unless there has been a sufficient space of time since the first stimulus. This period varies with the temperature of the nerve. At 4° C. the smallest interval is 0.008 second; at 2° C., 0.012 second; and at about 15° C., it is 0.002 second.

This has an important bearing in explaining the lack of sensation and motion from the application of high-frequency currents, in which the impulses occur in opposite directions at intervals of less than $\frac{1}{1,000,000}$ second.

Delay of Electric Response of a Nerve to a Second Stimulus.—The greatest delay occurs when the interval between the two electric stimuli is $\frac{5}{1000}$ second.[5] And S. Levinson has further experimented with two electric stimuli, the first producing a marked but not a maximal contraction. With intervals varying from 0. to 0.0004 second, the two stimuli reënforce each other. Longer intervals result in a lesser contraction than if only the second and stronger stimulus were applied, and beyond a certain still longer interval the result is the same as if only the second were used.[6]

Effect of Heat and Cold on Nervous Excitability.—K. Pretschistenskaja[7] has found that the electric excitability of the vagus nerve is tolerably uniform, within quite wide limits. It is diminished either above or below these limits. Heat or cold does not increase its excitability beyond the normal.

G. Brodie and W. D. Haliburton[8] have studied the effect of heat upon muscles and nerves. The electric excitability of muscles and nerves and their negative variation and other electrophysiologic properties disappear at about the temperature of 40° C. in frogs, 47° C. in

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[1] C. R. Soc. de Biol., eleventh series, 1, 386, May 20, 1899.
[2] Skandinavisches Archiv. f. Physiologie, vol. xxiii, p. 1, 1909.
[3] G. Weiss, C. R. Soc. de Biol., tenth series, 6, 103, February 11, 1899.
[4] Journal of Physiology, xxiv, 417–426, 1899.
[5] P. Gotch, Journal of Physiology, xl, p. 250, 1910.
[6] Archiv. für die gesam. Physiologie, cxxxiii, 267, 1910.
[7] Zeit. f. Exp. Path. u. Therapie, 47, 87, p. 97, 1905.
[8] Journal of Physiology, 32, 473, 1905.

mammals, and 50° C. in birds. The difference is due to the varying coagulability of the proteid substances.

J. Carvallo and G. Weiss[1] have experimented upon the influence of temperature upon the disappearance and reappearance of muscular contractility.

Marey's drum and a very slowly revolving myographic cylinder were used. The muscle was stimulated by the secondary current from an induction coil. A condenser was discharged through the primary of the induction coil every few seconds. This *method of electrically stimulating muscles was suggested by d'Arsonval*, and prevents polar or electrolytic effects. The experiment was performed upon a frog's gastrocnemius, the animal being pinned to a piece of wood and placed in a vessel of water whose temperature could be regulated. A weight of 10 grams was tied to the foot: 1. In a living frog with the sciatic nerve cut, but the circulation intact at 20° to 25° C. muscular excitability was practically inexhaustible, but at first there was a slight increase in electric excitability, followed by a decrease with a subsequent increase to about three-fourths the original height of muscular contraction. This latter height was uniformly maintained for a very long time. Fatigue takes place when the temperature is raised or lowered. It occurs very rapidly at 0° C., but contractility instantly returns on raising the temperature to 20° C. The same fatigue occurs at 30° C., but there is not the same recovery on reducing the temperature from this level to 20° C. 2. A frog which is cut in two to stop the circulation presents similar results. For instance, at 0° C. it takes only one-half hour for fatigue to reduce the electric contractility to zero.

Effects of Cold Upon Speed of Nerve Conduction.—The accepted formula is Log. $K = a + bt$, a and b being constants for most temperatures. And at two different temperatures, 10° C. apart, the ratio is between 1 to 2 and 1 to 3. Cold, then, greatly slows the transmission of nerve impulse. The ratio is similar to that of the effect of cold upon ordinary chemic reactions (Vant Hoff's law), but many experimenters do not regard it as a purely physical as distinguished from vital phenomenon.

Effect of Alternating Currents.—A closing and sometimes also an opening contraction takes place when an alternating current of medium frequency is turned on or off.

Stimulation of a Muscle Which is Completely Separated from the Body.—W. Fröhlich[2] finds that the effect depends upon the portion of the muscle to which the current is applied. The greatest effect upon a detached muscle is produced when the electrodes are applied near the middle of the muscle and when the current traverses the length of the muscle. The least effect is produced when both electrodes are applied at the distal extremity of the muscle.

Electric Contractility of Striated Muscle After Death.—J. Babinski[3] finds that the muscles of the face present a phase in which their direct voltaic excitability (electrode applied to the muscle) is retained, while direct faradic excitability and indirect voltaic excitability (electrode applied to the nerve) have disappeared. The reaction obtained by direct voltaic stimulation is ACC>CaCC and CaCC>AOC.

Marié and Cluzet report the same results in the same journal.

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[1] Journal de Physiol. et de Path., 990, 1899.
[2] Arch. f. Experiment. Pathol. u. Pharmacol., 5, 317, 1905.
[3] C. R. Soc. de Biol., 1899, eleventh series, 1, 343, May 6, 1899.

Stimulation of Nerves by Electric Currents of Very Brief Duration.—Louis Lapicque[1] finds that the contraction produced by a very brief electric stimulation is exclusively a closure contraction.

J. L. Hoorweg[2] calls attention to the fact that the muscle is not a mere electrodynamometer, indicating the strength of the nervous impulse arising from stimulation of the nerve, but is itself excitable. Engelmann's observation in 1871, that the ureter which is of unstriped muscle devoid of motor nerve-fibers, obeys the same laws of electric excitability as nerves or muscles which are supplied by nerves. Burdon Sanderson's observation that curarized muscles obey the same laws of electric stimulation as nerves confirms this fact. Hoorweg considers Weiss's law of electric excitability to be true only of short discharges and that it is in this case deducible from Hoorweg's law. He thinks Weiss's law leads to error when applied to currents of considerable duration, while its simplicity makes it very useful for currents of short duration. Lapicque's correction for currents of short duration seems unsatisfactory to Hoorweg, because it assumes an absolute constancy of resistance.

Tonus Rhythms in Normal Human Muscles.—T. A. Storey[3] provoked a series of contraction in the abductor indicis by a magnetoelectric apparatus, and made tracings which showed the presence of tonic contractions analogous to those demonstrated by Joteyko in veratrinized frogs' muscles. The same experiment upon a cat whose sciatic nerve had been divided showed that the tonic contraction was of peripheral origin.

Apparent Inhibition of Muscular Contraction.—The experiments of a number of different observers, including F. B. Hoffman,[4] show that there are no inhibitory nerves to the voluntary muscles.

Contraction of Degenerated Muscles When Stimulated by Electricity.—G. Guerini[5] has experimented upon frogs. Normally, a series of identical stimuli at sufficient intervals of time produce contractions of about the same form and height, but in the case of degenerated muscles the contractions are unequal, their excitability varying within wide limits. Normal muscles are more excitable; degenerated muscles present the opposite condition. Finally, in degenerated muscles great frequency of stimulation gives a greater contraction at the cessation of the currents than at the beginning (opening contraction is greater than closure contraction).

Drug Effects which Stimulate those of Electricity.—The clonic and fascicular muscular contractions which are produced by electric stimulation of the motor nerve-trunks may be very closely imitated when certain drugs are administered. Hexamin-cobalt chlorid given to frogs, even in very small non-toxic doses, produces this effect.[6]

Du Bois-Reymond noted that the central cut end of the sciatic nerve in a strychninized frog shows a negative variation at the moment when a convulsion takes place.

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[1] C. R. de Biol., 58, 314, February 16, 1905,and C. R. Acad. des Sciences, 140, 537, February 20, 1905.

[2] Arch. f. d. ges. Physiol., 103, 113, 1904.

[3] Jour. of Physiology, 12, 75, 1904.

[4] Biologisches Centralblatt, 103, 291, 1904.

[5] Lo Sperimentale, 59, 187, 1905.

[6] J. Bock, Arch. f. exp. Path. u. Pharmacol., 30, 1904.

Return of Excitability After Peripheral Nerve Transplantation.—Peterson[1] reports a case of accidental division of the median and ulnar nerves. The condition five months later was one of trophic disturbance in the fingers, anesthesia, contracture and atrophy of the muscles of the thenar and hypothenar eminences, with reaction of degeneration. The ends of the nerves were sutured, interposing 4 cm. of a dog's sciatic nerve. Sensation returned in the thumb in twenty-four hours, in the palm in eight days, and progressively over the hand in twenty-one days, and the trophic ulcers healed. Motor power had returned in two months. There have been more than a score of such cases, and Peterson states that regeneration is due to the prolongation of axis-cylinders from the central into the peripheral portion. Sensation returns first.

Absence of Inhibitory Nerves in Voluntary Muscles.—There are probably no inhibitory nerves to the skeletal muscles—the ordinary voluntary muscles. The reduced response to successive stimuli is not due to the stimulation of an inhibitory nerve, but is a phenomenon of fatigue. This is made up very slightly of a reduction in the conductivity of the nerve, and chiefly of a diminished functional capacity of the muscular fibers and a diminished excitability of the terminations of the nerve, and of the muscular fibers immediately after each stimulation. Later there is a return to the normal, but this takes place the more slowly the greater has been the fatigue.[2]

Speed and Duration of Nervous Stimulation.—The speed of propagation of a nervous impulse after unipolar stimulation is about 26.43 meters a second.[3]

The stimulation produced in the nerve is an oscillatory condition lasting about 0.00134 second.[4]

Excitability of a Nerve at Different Parts of its Length.—Budge and Pflüger have noted a diminution of electric excitability toward the periphery in motor nerves, but, according to Munk and Schultz, this may have been due to traumatic changes. I. Munk and B. Schultz[5] have arrived at the conclusion that the excitability of the phrenic nerve is the same throughout its entire course. This implies that the transportation of nervous impulse does not consume any sensible amount of energy, and hence does not produce appreciable fatigue.

K. Eickhoff[6] found that the excitability of a frog's sciatic nerve is the same from top to bottom for abrupt electric stimuli, but it is twice as great above as below for gradually increasing stimuli.

REFLEX STIMULATION BY ELECTRICITY

G. A. Pari[7] has studied the relation between the intensity of the stimulation and the height of the resulting contraction. Generally, the stronger the stimulation of a centripetal nerve is, the greater number of muscles respond reflexly and the stronger is their response.

N. Uschinsky[8] has studied the fatiguability of the reflex apparatus

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[1] American Journal Medical Sciences, April, 1899.

[2] F. B. Hofman, Arch. f. d. gesam. Physiologie, vol. ciii, p. 291, 1904.

[3] Aug. Charpentier, C. R. Acad. des Sc., cxxviii, 169, June 16, 1899.

[4] Ibid., cxxix, 38, July 3, 1899.

[5] Arch. of Physiol., 281, 1898.

[6] Arch. f. d. ges. Physiol., lxxvii, 156, 1899.

[7] Arch. Ital. de Biol., 42, 109, 1904.

[8] Centralbl. f. Physiol., 13, 4, April 1, 1899.

in the spinal cord. The weakest faradic current which will produce reflex contraction in a frog becomes ineffective if continued for a minute and a half. It becomes effective again after a few minutes' rest, even if reflex excitability has been suspended during twenty hours continued faradization.

Negative Variation from Reflex Stimulation.—Reflex nerve activity is accompanied by the electric phenomenon of negative variation. J. Bernstein[1] has experimented upon this subject, stimulating one branch of the sacral plexus, while making electrometric measurements of another branch. There is a strong reflex electric reaction which is propagated from a sensory nerve to a motor nerve, but not from a motor to a sensory nerve. Stimulation of the posterior root of a spinal nerve produces a negative variation in the anterior root, but stimulation of the anterior root does not produce a negative variation in the posterior root. Since the negative variation travels through sensory or motor nerves in either the physiologic or the contrary direction, the conclusion is drawn that it is in the dendritic ramifications that the restriction of the reflex electric propagation to the physiologic direction takes place.

The latent period of reflexes is best shown by the time required for the appearance of an electric current after the patellar tendon, for instance, has been struck. Paul Hoffmann[2] finds that this is normally about 0.019 second.

No Reflex Tetanus.—S. Baglioni[3] finds that the cord cannot respond to repeated stimulation of a sensory nerve by the production of reflex tetanus. This is true in the frog, even when the motor excitability has been heightened by the injection of phenol. And as the direct stimulation of the motor elements may cause tetanus, the difference is solely in the sensory cells of the cord, which have a long refractory period of one-fourth or one-half second. Sufficiently spaced stimulation of the proximal end of the sciatic nerve in a phenolized frog produces reflex contractions, but if the rapidity of the stimuli is increased, irregular clonic reflex contractions may ensue, or there may be simply an initial contraction, followed by a passive condition.

Reflex Elongation of Muscles.—G. A. Pari[4] stimulated the peripheral end of the sciatic nerve in a recently decapitated winter frog, and produced elongation of the gastrocnemius muscle in the other leg. This was generally observed with weak currents. Successive stimuli of the same strength sometimes cause reflex elongation and sometimes reflex contraction. This is connected with oscillations in the reflex excitability of the cord.

C. S. Sherington and S. C. Sowton[5] show by experiments upon a decerebrate or "spinal" dog or cat that increasing the galvanic or faradic current applied to a centripetal or afferent nerve produces not a reflex contraction, but, on the contrary, a relaxation of the muscles at the other extremity of the reflex arc. The same relaxation ensues when weak galvanization is changed to weak faradization. The same experimenters show[6] that just as chloroform reverses the pressor reflex effect of

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[1] Arch. f. d. ges. Physiol., 73, 374, 1899.

[2] Archiv. für Physiologie, 223, 1910.

[3] Ibid., 4, 113, 1904.

[4] Zeit. f. Allge. Physiol., 4, 127, 1904.

[5] Zeit. für allgemeine Physiologie,, xii, 484 1911.

[6] Journal of Physiology, 1911, xlii, 348.

stimulation of an afferent nerve, so chloroform makes the reflex an inhibitor one and strychnin a motor one.

Stimulation of Antagonistic Muscles.—G. A. Pari and A. Farini[1] have made experiments with electric stimulation, and they publish myographic charts which show that there is a certain physiologic unity between the motor nerves going to a muscle and its antagonist. Such muscles are the gastrocnemius and the anterior muscles of the leg. Stimulation of a nerve-center which causes contraction of a given muscle causes simultaneous relaxation of its opposing muscle.

Leon Asher[2] has made further studies upon antagonistic nerves, using electricity in some cases as the means of stimulating the nerve-centers.

Sensory and Other Effects from Stimulation of the Cervical Sympathetic.—Ch. A. François-Franck[3] has made experiments which lead to the following conclusions:

1. Stimulation of the cephalic segment of the cervical sympathetic causes vasomotor and cardiac stimulation (increase in blood-pressure and more rapid heart action). Hürthle attributed this to cerebral anemia, just as in the case of compression of the carotid artery, but François-Franck says that stimulation of this part of the sympathetic sometimes causes the opposite effect of vasodilatation and slowing of the heart's action; and that in either case it is due to a reflex effect from centripetal impulses carried by the sympathetic to the cardiovascular centers in the medulla, and not to a direct stimulation of cerebral vasoconstrictors, with accompanying cerebral anemia.

The circulatory effect is the same as that produced by stimulation of the anterior crural nerve, but it requires a much stronger current than the latter.

2. General circulatory changes are produced by stimulation of the medullary segment of the vertebral nerve, the deep division of the cervical sympathetic, and these also are of reflex origin.

3. This transmission of centripetal impulses from the lungs and other organs by the sympathetic nerve causes it to be a necessary factor in the reflex regulation of the circulatory functions. This is a contraindication to the removal of the cervical sympathetic, as sometimes performed for the treatment of exophthalmic goiter, epilepsy, idiocy, and glaucoma, on the theory that its functions were purely centrifugal.

Stimulation of the upper segment of the cervical sympathetic carefully isolated from the pneumogastric may cause diminished tension in the aorta, due to multiple vasodilatation, both superficial and deep. Among the latter effects are active congestion of the opposite lobe of the thyroid gland.

The circulatory effects may, therefore, be either *pressor* or *depressor*, and the effects upon respiratory, general motor, pupillary, and secretory functions also differ in some cases.

The *heart* is slowed when the stimulation of the sympathetic produces a depressor effect, but more often the effect is a pressor one, and then the heart action is either rapid or normal.

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[1] Atti del R. Istituto Vinetto di Scienza, Lettere ad Arti. 64, second part, 929, 1904, 5.

[2] Zeit. f. Exp. Path. u. Therapie, 47, 87, 1905.

[3] Journal de Physiol. et de Pathol., 1899, 724.

Respiration may change in rhythm, frequency, or fulness. There is sometimes a reflex spasm of the bronchi and pulmonary vessels. This reflex, through stimulation of the sympathetic, may explain the dyspnea which occurs in some morbid conditions of the aorta.

The opposite *pupil* may be dilated.

The fingers may *perspire.*

There is increased secretion of *saliva.*

As a final experiment, François-Franck cut all the filaments anastomosing with the cervical, hypoglassal, spinal, glossopharyngeal, pneumogastric, and trigeminal nerves, but left the anastomoses with the carotid plexus. Stimulation of the sympathetic then produced vasomotor effects without the other reflex effects.

Circulatory Changes from Stimulation of the Peripheral End of the Cervical Sympathetic.—E. Wertheimer and L. Lepage[1] exposed the inferior and the first thoracic or stellate ganglion. Following the cutting of the sympathetic nerve above this point, there is an irregularity of cardiac rhythm, and this same irregularity is found when the peripheral end of the divided sympathetic is stimulated, and also when the intact sympathetic is stimulated. The latter is not so desirable for this experiment, because it produces sensory symptoms and requires an anesthetic.

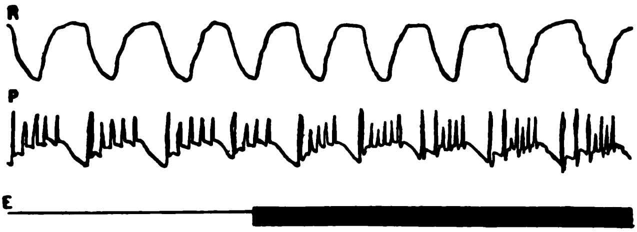

Fig. 249.—Circulatory effect from stimulation of the peripheral end of the divided sympathetic. R, respiration; P, pulse; E, electrical stimulation (Wertheimer and Lepage).

Effect Upon the Pupil from Stimulation of the Sympathetic.—Lewandowsky[2] has experimented upon both warm- and cold-blooded animals. He finds that in the former, stimulation of the nerve above or below the superior cervical ganglion causes a contraction lasting five to ten seconds, while in cold-blooded animals it lasts very much longer. The muscles controlling the size of the pupil are non-striated. The duration of contraction is in direct proportion to the strength of the current. The make discharge from an induction coil either gives no contractions or only short weak ones. The opening discharge gives very much stronger contractions. The myographic curve shows an abrupt ascent and a much slower descent.

Vasomotor Effects on the Small Intestine Produced by Stimulation of the Central End of the Pneumogastric.[3]—Stimulation of the central end of the vagus in dogs produces, in some cases, dilatation

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[1] Jour. de Physiol. et de Pathol., 1899, p. 238.

[2] Arch. of Physiol., 1899, 352.

[3] J. L. Bunch, Proceedings of the Physiological Society, Journal of Physiol., 1899, 24.

or constriction of the intestinal blood-vessels. In either case there is an increase in the general blood-pressure, but the vasodilatation may be obtained even when the blood-pressure is maintained at a constant level by hydrostatic means. If the splanchnic nerves are cut, stimulation of the central end of the vagus is not followed by vasodilatation of the intestine.

In a cat, stimulation of the vagus always causes dilatation of the intestinal vessels, accompanied by a fall in the general blood-pressure.

Stimulation of the Pneumogastric and its Motor Effect on the Small Intestine.—D. Courtade and J. F. Cyon[1] find that strong stimulation of the pneumogastric nerve in the thorax produces a contraction of the longitudinal muscular fibers which is followed by their relaxation, and later by a contraction of the circular fibers. This contraction differs in character of progress and in rapidity from the effect produced by stimulation of the sympathetic.

J. L. Bunch[2] obtains the same results by stimulating the pneumogastric in the neck.

Reflex Vasodilatation from Stimulation of the Sciatic Nerve.—I. N. Bystrenine[3] made experiments on cats and dogs. He found that electrization of the sciatic nerve by a current of medium intensity is followed by vasoconstriction, while weaker or stronger currents produce vasodilatation.

Stimulation of the peripheral end of the sympathetic, at the level of the fifth or sixth lumbar vertebra, does not produce vasodilator effects, contrary to the opinion of Ostroömov.

Motor Effects Upon the Stomach from Stimulation of Different Nerves.—D. Courtade and J. F. Cyon[4] find that:

1. Stimulation of the intact pneumogastric, or of its peripheral end if it is divided, causes contraction of the longitudinal fibers, then of the circular fibers, then relaxation of the longitudinal and later of the circular fibers, and then a period of rest. There may be a relaxation of the circular fibers at the cardia and pylorus, simultaneously with the contraction of the longitudinal fibers.
2. Stimulation of the peripheral end of the great splanchnic arrests peristalsis and at the same time causes tonic contraction of the circular fibers, especially at the cardia and pylorus, and also relaxation of the longitudinal fibers.

The contractions produced by pneumogastric stimulation are abrupt and of short duration, while those from splanchnic stimulation are more like changes in the state of tonic contraction of the unstriped muscular fibers.

Effect of Direct Electrization of the Stomach Upon its Secretory Activity.—K. Freund[5] finds that this does not effect the secretion of gastric juice, but only causes a moderately increased mucous secretion, which is more or less strongly alkaline.

Effect of Direct Stimulation of the Heart.—*Effect of Intracardiac Electrization.*—The current from two ordinary voltaic cells and the extra current from a small electromagnet, passing between electrodes placed

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[1] C. R. Soc. de Biol., tenth series, 6, 25, January, 1899.
[2] Jour. of Physiol., xxv, 22, 1899.
[3] Nevs. Vestnick, 12, 284.
[4] Jour. de Physiol. et de Pathol. Gen., 45, 1899.
[5] Arch. f. Path. Anat. u. Physiol., 180, 238, 1905.

inside the ventricle of a horse's heart, has caused almost instantaneous death. This happened in an experiment by A. Chauveau,[1] who was studying the movements of the valves of the heart. A thin insulated stem was passed through the carotid artery, aorta, and aortic valves. It contained a spring which closed an electric circuit when pressed upon by the contracting valves. This current actuated a small electromagnetic signal, an extra or self-induction current from the coils of this passed through the blood in the ventricle, when the aortic valves opened and allowed the contact to be broken. This occurred at each pulsation of the heart, which was tremendously accelerated, and the animal died almost immediately. The currents were so weak that they could not be felt when the tip of the tongue was applied to the point where the contact was made and broken. The fatal effect upon the heart was prevented in further experiments by establishing a short circuit for the extra current at each make and break.

Effect of Induced Currents.—Tetanic contraction was produced in Danilewsky's experiments upon different warm-blooded animals.[2] A living rabbit's heart was isolated by Langendorff's method, and hot Ringer's solution saturated with oxygen circulated through its coronary arteries. It had its apex in contact with two electrodes from an induction coil, giving currents perceptible to the moistened finger. The heart was in a condition of lessened vitality and extremely sensitive to currents from an induction coil or from a magneto-electric machine. Weak or medium currents produce a tetanic contraction of the ventricles, while the rhythmic contraction of the auricles continues. This contraction may be maintained for two and a half minutes, and is followed by a pause succeeded by a very ample systole. Stronger or more frequently interrupted currents do not produce as vigorous contraction or as complete tetanus. It is extremely difficult to produce tetanus of the heart with the latter *in situ* and uninjured. It may be obtained, however, when the refractory period (or latent period of muscular contraction from electric stimulation) is diminished by poisons or pathologic changes, or when there is hyperexcitability or hypodynamia.

A. Bohme's experiments[3] upon a frog's heart whose electric excitability has been destroyed by chloral poisoning show that it is restored by camphor.

Experiments by Franz Müller[4] show that, in human beings suffering from tetanus or lock-jaw, there is no electric hyperexcitability of the heart. This organ differs from the striated muscles, such as the diaphragm, in this regard.

V. Duchesi's experiments[5] upon a frog's heart slowly poisoned by phosphorus show that electric excitability diminishes very rapidly, as well as the height of the contraction produced by electric stimulation.

The heart may be made to pulsate by direct electric stimulation, even while it is in a state of arrest from electric tetanization of the pneumogastric nerve. M. Stasser[6] performed an experiment upon

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[1] Journal de Physiologie et de Biologie, 381, 1899.
[2] Biologisches Centralblatt, cix, 596, 1905.
[3] Journal de Physiol. et de Pathol., 1905.
[4] Deutsch. Arch. f. klin. Med., 61, 632.
[5] Arch. ital. de biol., xxxi, 232, 1897.
[6] Arch. internat. de Physiologie, 2, 259, 1905.

dogs' and rabbits' hearts, one electrode on an auricle and the other on the corresponding ventricle. An isolated induction shock causes a systolic contraction occurring simultaneously in both, but preceded by a latent or refractory period of 0.06 second. The same stimulation with both electrodes applied to the auricle causes an auricular pulsation after a latent period of 0.06 second, and this is often, but not always, followed 0.08 or 0.12 second later by a ventricular contraction. Applying the stimulus to the ventricle it takes three times as long for the subsequent auricular contraction to occur.

F. Philips[1] has made an experimental study of the fibrillary tremors produced in the heart by electricity. He found that fibrillation of the auricles produced by direct stimulation does not arrest the ventricles, but gives them a disordered rhythm (Kronecker and Spalita do not agree with this statement). He found that as soon as the auricular tremor gives place to regular contraction the normal ventricular rhythm is resumed. Stimulation of the pneumogastric prevents the occurrence of auricular fibrillation from electric stimuli (this contradicts Kronecker and Spalita), and also the disturbing effect of auricular stimulation upon the ventricles.

Mild stimulation of the pneumogastric inhibits the effect of direct stimulation of the heart, and causes the ventricles to return to their normal rhythm.

Powerful stimulation of the pneumogastric arrests the pulsations of the heart.

E. Hedon and T. Arrows[2] have experimented with electric stimulation of the isolated myocardium or the muscular substance of the heart in a living rabbit. The effect is to relax the muscular fibers and to prolong the ensuing diastole. The same effect is produced by stimulation of a heart poisoned by atropin. Severe nicotin-poisoning in a dog increases the electric excitability of the heart and makes it more persistent.

Reflex Cardiac Stimulation as Modified by Certain Poisons.—Under normal conditions, stimulation of most of the sensory nerves leads to a reflex increase in cardiac energy. This can be accurately measured by noting the increase in the blood-pressure in the arteries and its reduction in the left auricle. F. Winkler[3] has found that while stimulation of the sciatic nerve in a healthy animal increases the work done by the heart by 364 per cent., there was an increase of only 146 per cent. in the same animal poisoned by muscarin (toad-stool poison). Sodium nitrite still further reduces the reflex cardiac stimulation, or it may even result in a reflex reduction of cardiac activity when the sciatic nerve is stimulated. And under the influence of amyl nitrite electric stimulation produces a reflex enfeeblement of 45 to 75 per cent. in the cardiac activity. It does not slow the tachycardia of amyl nitrite, though it does slow the normal pulse; and it increases the tachycardia of sodium nitrite and increases the rapidity of the extremely slow-beating heart of muscarin-poisoning.

Electric Stimulation of a Nerve-center, or of the Spinal Cord, or of a Nerve.—This excites the function of the part stimulated, and a muscular movement or a sensation or some other effect is produced.

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[1] Arch. internat. de Physiologie, 2, 271, 1905.
[2] Journal de Physiol. et de Pathol., 1899.
[3] Zeit. f. klin. Med., 36, 138, 1898.

Applied to different parts of the cortex of the brain, it has given us the most valuable and minute localization of brain function, and applied to the different other parts of the cerebrospinal and sympathetic nervous systems, it has decided many problems as to function which were not to be determined by experimental physiology without the use of electricity.

The varying physiologic effects have a direct bearing upon the therapeutic use of electricity.

Stimulation of the olfactory centers in the brain causes the same disturbance of respiration that is produced by the inhalation of ammonia and similar substances. Dyspnea may continue even after the stimulation has ceased.[1]

Electric Stimulation of the Optic Nerve does not Produce the Sensation of Light.—This is the surprising result of a series of operations upon six different human patients in whom the optic nerve was laid bare and subjected to electric stimulation. Other stimuli, chemical or mechanical, gave the same result.[2]

Electric sensation is quite distinct from that of pressure or heat, etc. A tuning-fork may be used to produce vibratory pressure and at the same time to transmit to the skin a faradic current for which the tuning-fork acts as the primary interrupter. The patient should be able to tell the difference between the pressure of the tuning-fork alone and when the electric current is added. Arrigo Tamburini has constructed an apparatus, called the *polyœsthesioscope,* by means of which sensations of warmth, vibration, pin-prick, and electricity may be tested separately or together.[3]

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[1] V. Ducheschi, Archive Ital. de Biol., lii, 183, 1910.

[2] S. Caldero, Archivo di farmacologia sperimentale et scienze affini, x, 11, 1910.

[3] Rivista sperimentali di Freniatri e Medicina legale delle alienazioni mentali, xxxvi, 977, 1910.

ELECTROPATHOLOGY

The harmful effects of electricity upon the human body have been observed in cases of lightning-stroke, accidents from contact with conductors charged with high-tension electricity, and undesirable effects from therapeutic application of electricity. Many experiments have been made upon animals, and have given us an exact knowledge of the dangers and of the means required to make safe use of this invaluable agency.

The effects may be anatomic or functional, general or local, and may be immediate or may not develop until later. The maximum effect is death.

Lightning-stroke.—The mechanically destructive results seen when a tree is struck by lightning are thought to be due to the sudden explosive expansion of gases. These are generated partly by simple vaporization from heating of the fluids in the pores of the wood, and partly by the electrolytic decomposition of these fluids. A man struck by lightning is not torn into pieces, but the same disruptive effect may occur and produce gross or microscopic changes. The gross changes occur as areas of destructive extravasation in different organs, and upon the surface at the places where the electric discharge entered and emerged from the body, and constitute the well-known lightning figures which have given rise to the most extraordinary theories in the scientific as well as in the lay mind. The microscopic effects are of a corresponding nature.

Lightning Figures.—Markings are found upon the surface of a person who has been struck by lightning, and these often have a branching appearance, suggestive of the trunk and limbs of a tree.

A thirty-one-year-old man, struck by lightning and thrown to the ground, stated that he did not lose consciousness; could not move his legs. He was bending over at the time he was struck. The lightning figures disappeared in two or three days. The deeper burns of the first degree led to a brownish diffuse coloring of the skin, which appeared eight days after the injury and became gradually darker. This pigmentation was to be seen as long as three years after the injury. Muscular weak-

Fig. 250.—Lightning figures upon a man's back (Jellinek).

ness remained for several weeks and no internal injury was evident. A year later he could work very well, although the left leg was weaker, and before each thunder shower he felt pain in both legs and in the lumbar region. The left leg, and especially the top of the foot, was slightly bluish in color and felt cooler. There was increased patellar reflex on the left side. Other cases have occurred in which a resemblance to other objects has been noted, and a man is now being exhibited in public places in America whose back is said to show a very striking picture of a crucifix in consequence of a lightning-stroke.

The explanation offered in Rockwell's excellent book "(Medical and Surgical Electricity," p. 160) can hardly be accepted at the present day. It is as follows: "The explanation of all these cases is the same. The particles of the tree reduced to great fineness by the electricity are mechanically transported and burned in the skin. The process is, therefore, not chemic, but mechanic and thermic."

The utter impossibility of this explanation lies in the fact that it requires us to think that particles from small parts of any individual branch of the tree, instead of flying off in all directions into space, fly right straight to a particular spot the size of a pin-prick on the surface of the patient's body. Particles from a branch four inches thick and fifteen feet long would, accordingly, have to reach the body only along a narrow line a few inches long.

The particles formerly supposed to be emitted from the trunk, branches, and even individual leaves would certainly produce a general blur, particles from each part of the tree affecting the whole surface which the particles could reach. There is no suggestion possible of a lens-like action in this case.

The correct explanation of these lightning figures seems to be that they are anatomic changes, erythema or extravasation, produced by the electric discharge applied at a certain part and extending into the deeper tissues or following the superficial tissues along the lines of least resistance. The latter lines depend partly upon the place of exit of the discharge and partly upon the direction of the blood-channels and other paths of comparatively good conductance. Then, again, the path of such a discharge of high-tension electricity starting from a point and extending through a medium which is not homogeneous has a natural tendency to be radiating and to branch and subdivide. A static spark applied to a photographic plate (pp. 45 and 52) illustrates this tendency in a beautiful manner.

In some cases the lightning-stroke does not cause branching figures, but simply a discolored surface.

The surface marks in a case of lightning-stroke do not necessarily correspond with the severity of the symptoms produced. These depend upon the organs which happen to form the conducting path between the places of entrance and of exit for the discharge, and may be death, loss of consciousness, deafness, temporary or permanent paralysis of different parts.

Death from Lightning-stroke.—This is generally accompanied by demonstrable lesions in the central nervous system, extravasations of blood, and areas of tissue disintegration. The person is usually rendered unconscious, and may be found without pulse or respiration. He may never show any signs of life or may respond for a while to appropriate treatment and still succumb to the paralyzing effect of the shock with or without special lesions in the respiratory or circulatory centers.

Treatment of Lightning-stroke.—As it is impossible to say from the condition of the patient immediately after the shock whether or not there are irremediable lesions, an effort at resuscitation should be made in every case. Wrapping the patient in dry warm blankets, performing artificial respiration with the patient recumbent, and a certain effort at cardiac massage by intermittent pressure applied just below the border of the ribs are most important. Hypodermics of cardiac or other stimulants may be given, but it is important here, as in every case in which the circulation has practically ceased, not to give an overdose. If one were to continue to give repeated injections of strychnin or digitalin because no effect was noted, so much might be given that if the heart did start up again and carry all these several doses into the circulation, the patient might be poisoned. Do not administer more than the proper total amount of a powerful drug in these cases, even if there is no perceptible response to it. The question of the employment of electricity as a means of stimulating the diaphragm or the heart may be considered in individual cases.

The Pathologic Effects of Static Electricity.—The high-tension currents produced by the static electric machines have such small quantity that the shocks they give if carelessly handled are incapable of producing serious pathologic lesions or even serious symptoms. While the effect of startling the patient is undesirable, the muscular contraction excited by a static spark is not of a painful character and is only momentary. A single static spark does not produce any change in the tissues, but a number of sparks applied to the same spot in a continuous stream will produce at first a white swelling of the skin from edema and this is followed by redness and in extreme cases by vesication and other evidences of a burn. The effect on the tissues is purely a local one, and is sometimes produced purposely as a counter-irritant. Its accidental production is to be avoided. For instance, in applying the wave-current or the static induced current, where one or both electrodes are fixed in position upon the skin, it is important that there should be a perfect conducting contact. If there is a place at which the current has to spark across to reach the skin, a slight burn will soon be produced.

If a person should accidentally receive the full charge of a static machine by touching the two poles at the same time, there would be a disagreeable jerk of the arms as they were involuntarily drawn away, but no serious result.

The element of electrolysis need not be considered in connection with the pathologic effects of the very brief and quantitatively small discharges of static electricity, though it is true that they are unidirectional and hence do produce a certain small amount of electrolysis.

Manner in Which Electric Accidents Occur.—The proverbial "ounce of prevention" is all important here. Many lives may be saved by the avoidance of dangerous electric contacts, which very often cause death or serious injury, in spite of the most skilful treatment, after an accident. Pictures by Jellinek, in his "Atlas der Elektropathologie," Vienna, 1909, show the many ways in which accidents have actually occurred. In a private house there should be no bare wires or uncovered knife switches and the fuses should be in a covered case. When it is necessary to handle any such part of the electric-light circuit, one should see that he is not standing in a wet place or upon metal of any kind; he should use only one hand, and should not at the same time touch any metal or anything connected with the electric-light circuit. If one hand happens to touch two oppositely charged surfaces it is disagreeable, but if both hands do so it is dangerous. And the same is true in

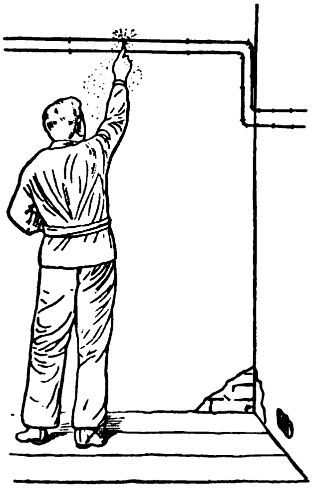

Fig. 251.—220 volts direct current short circuited; superficial impregnation of the skin of the hand and of the face with particles of metal. The current should have been turned off before he began to do this work (Jellinek).

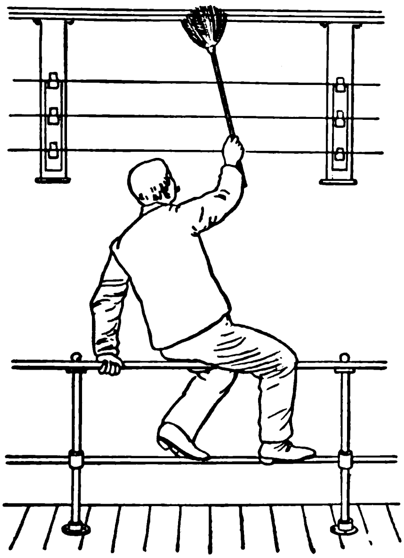

Fig. 252.—Alternating current, 5500 volts Immediate death with burns of the right hand and scrotum; the lungs were free, rich in blood, and moist. At the back part of the left upper lobe there was a reddish gray nodular focus empty of air. The pleura over this was smooth; only a single washed out ecchymosis under the right pleura (Jellinek).

regard to touching an electrically charged surface with one hand and making a ground connection at the same time.

In electric laboratories and power-houses there are many bare charged surfaces and the currents are often of high tension. The attendants should, of course, be instructed in the danger of touching any object charged to a high potential and of touching any two charged objects or a charged object and any other metallic object.

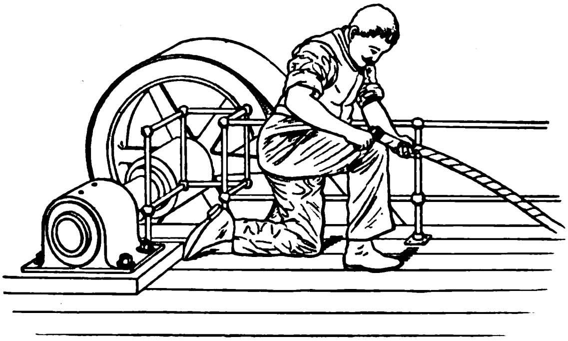

Fig. 253.—Alternating current, 5000 volts. The patient did not immediately become unconscious, but two days later the pulse went up from 106 to 180 and two days after that he died from burns of the arms, face, and knee (Jellinek).

Fig. 254.—Alternating current, 220 volts. Death with appearance of symptoms of acute edema of the lungs and lung and heart paralysis. There was a slight mark like a cut on the face and in front of the ear; otherwise he looked perfectly natural. No other visible marks external or internal. It seemed as if the cut were made mechanically and not by electric current; the hair was not singed (Jellinek).

It should be the duty of the constructing engineer to provide a platform of dry wood covered by a rubber pad, wherever an attendant has to stand while lubricating or cleaning, or regulating any part where there is an uninsulated charged surface; and also to provide similar non-conducting guard rails for the attendant to steady himself by when working

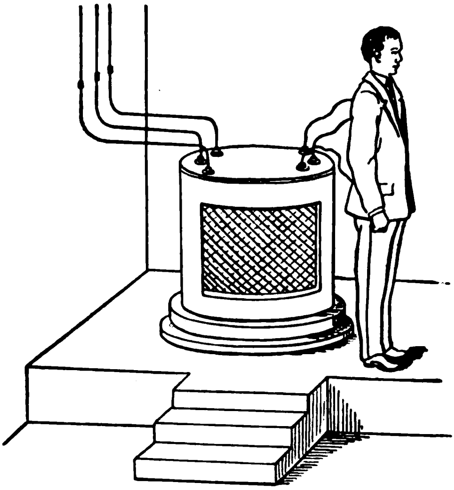

Fig. 255.—Alternating current, 10,000 volts. Death after taking three steps forward. Burns of the back and the right arm; no postmortem changes to be discovered (Jellinek).

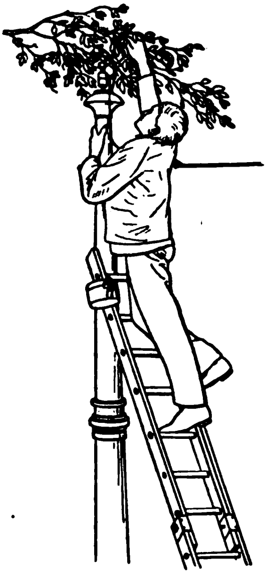

Fig. 256.—Direct current, 500 volts. Burns of right and left hands; fell 6 meters, sustaining a fracture of the base of the skull, and was picked up dead. He apparently had breathed superficially for a few minutes (Jellinek).

near any live surface. Of course, a "live wire" should not be touched, but the danger is obviated when the man is insulated from connection with the ground or any metal or liquid.

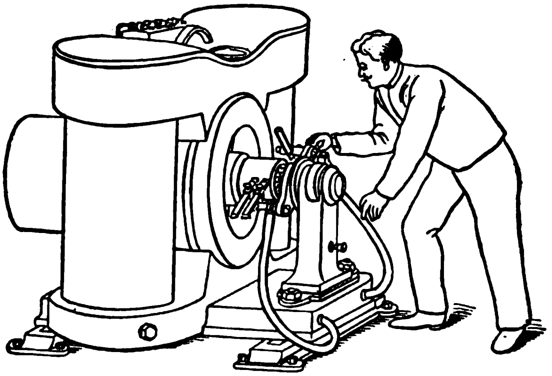

Fig. 257.—Alternating current, 4000 volts. Burns of the fingers of both hands; cried for help, was quickly freed from the contact, and was able to walk with assistance. The man made a good recovery (Jellinek).

Danger from Ordinary Electric Lights and Telephones.—An electric lamp or a telephone should never be touched with one hand while the other hand touches any water or metal, making a ground connection. Jellinek's pictures (Figs. 251 to 260) show terrible accidents caused in this way. It should be a rule not to place an electric light or a telephone

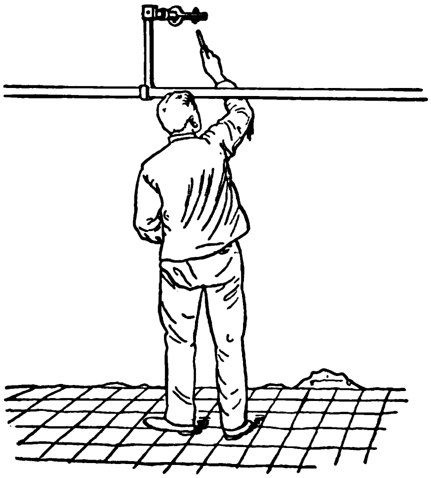

Fig. 258.—Alternating current, 5000 volts. The current entered at the forearm and went out at the elbow. Burns at both these places. He remembered the occurrence, and was conscious until the moment later when the current was cut off by an automatic break. Artificial respiration was successfully performed and he was able to go home (Jellinek).

within reach of a wash-stand or bath-tub or any metal rail or the like. The slightest displacement of one wire or the other in an electric-light socket may convert the exposed metal part into a charged surface, giving only a disagreeable shock to a person who is insulated, but dangerous to one through whom a ground connection takes place. The same danger is liable to occur from the telephone if a telephone and electric

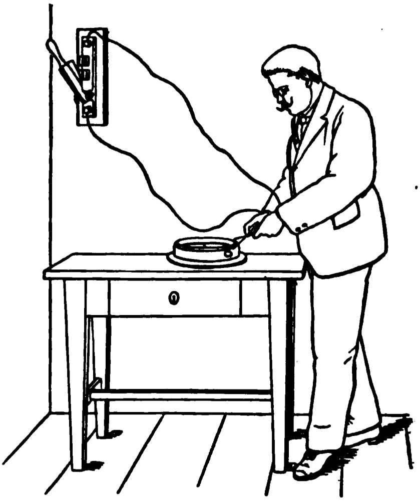

Fig. 259.—Electric engineer. Alternating current, 220 volts. Right hand reddish-brown burn. Eyes only saved by the eye-glasses, which were flecked with particles of metal burnt into them (Jellinek).

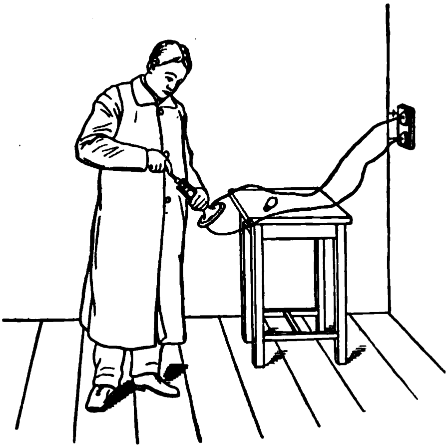

Fig. 260.—Alternating current, 220 volts. Called for help and told them to pull out the contact plug at the wall socket. Left-hand fingers all burned. Right hand showed no changes until sixteen days later, then flat white necrotic areas. No other symptoms or lesions (Jellinek).

wire have become "crossed." Rubber gloves and the various other precautions must be insisted upon in all work upon high-tension wires.

Fig. 261.—Touching electric lamp socket with one hand and the metal fixture with the other. Very severe accident.

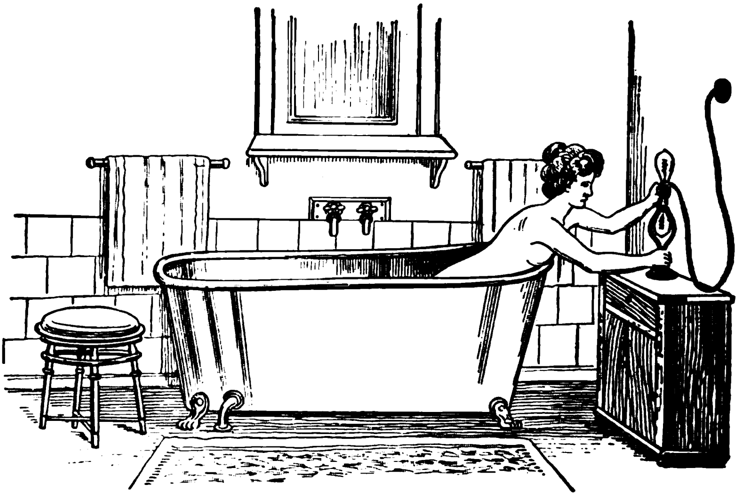

Fig. 262.—Handling electric lamp socket while in the bath. Fatal accident.

Pathology of Very High-tension Industrial Currents.—The electric transmission of power for long distances is most economically effected by the use of an alternating current of very high voltage. The power for all the street-car systems of the city of Buffalo is sent from Niagara Falls, about fifty miles away, in the form of an alternating current of 60,000 volts. The weight, and consequently the expense, of the copper conductors required for the transmission of the required number of horse-power in the form of a current of 600 volts would be 100 times as great. The higher tension current is, therefore, used for the long-distance transmission, and is reduced to the utilization tension of 550 volts by suitable transformers in the city where the power is to be used.

The tension of 60,000 volts is so great that it will spark across an air-space of a dozen inches, and the amperage carried by these conductors is very great. It means death under most circumstances to receive a discharge from one of these conductors, and so they should be guarded in such a way that no one can come near them. The lesions produced are very much the same as those produced by lightning: burns at the point of entrance and of exit, and areas of disintegration and extravasation in the organs traversed by the current. If both wires were touched, death would be practically certain unless the two points of contact were close together and upon the same limb. Even then a terrible burn would be produced, with probably permanent impairment of usefulness in the limb. If the man were holding the wire when the current was turned on, muscular contraction would cause the hand to grasp the wire with a grip which could not be released voluntarily. It would be practically sure death for any one else to try to release him except by promptly turning off the current.

If only one wire is touched, the current emerges from the body at the place where a connection is made with the ground. And the strength of the current traversing the body will depend upon the nature of this ground connection. A man wearing dry rubber overshoes and standing upon a dry wooden floor would receive less current than if he were standing upon a metal floor and had nails in his shoes. Then, again, rubber gloves would diminish the strength of the current. But with an alternating current of 60,000 volts these would usually all fail to prevent a fatal accident. There is probably no way in which live wires at this voltage can be safely handled. Death occurs from irreparable lesions in the central nervous system paralyzing both respiration and circulation. Treatment in accidents with such a voltage is generally unavailing.

High-tension Currents of 1000 to 10,000 Volts.—These are alternating currents employed in power transmission, and accidental contact with the conductors is usually fatal. Here, however, the tension is so much less than in the case of lightning and of the currents of 60,000 volts that many of the circumstances already alluded to may prevent a fatal amount of current from traversing the body. The injuries produced by the full strength of the current passing through the body from head to feet are similar to those from lightning or the 60,000 volts current: burns at the places of contact and areas of disintegration and extravasation, especially in the central nervous system. Death results from destructive lesions in the circulatory and respiratory centers.

The body may form a complete short circuit between the two wires or it may be in contact with only one wire and the ground. The current passing through the body from one hand to the other might be fatal, but might be recovered from. It has a tendency to produce muscular contortions and an involuntary gripping of the wires and respiratory or cardiac paralysis. Other portions may be traversed by a current of this strength, and if means are taken to resuscitate the patient from the general shock to the nervous system, recovery may take place with or without permanent impairment of certain muscles of organs.

Treatment is the same as recommended in cases of lightning-stroke. It is of the utmost importance that these cases should be treated as if they were merely stunned by the shock: not given up as dead without an effort at resuscitation. Either the heart or the respiration may be paralyzed to such an extent as never spontaneously to renew their functions and the patient still be in a condition to be saved by artificial respiration, warmth, and stimulants.

The question of primary cardiac or primary respiratory paralysis is answered by the statement that in some of these cases one is true and in others the other condition is produced. Even such elements as the nature of the clothing worn by the victim and the condition of the skin as to moisture may have a determining effect upon the path of the current through the body and the quantity which reaches particular organs.

Electrocution.—An alternating current of 1700 volts from a dynamo applied by means of metal bands passing around the head and the ankles sometimes requires several applications before life is extinct. These are of only a few seconds each and the entire process occupies only a very few minutes. It is probable that complete insensibility is produced instantaneously, but involuntary muscular contractions and the fact that more than one application is sometimes required make it a distressing sight for those whose duty it is to witness it. The different elements which prevent a good contact with the body or provide a path for the transmission of the current along the surface of the body instead of through it are responsible for occasional unsatisfactory results. Death is due to respiratory paralysis and it is in cases in which respiration begins again that additional applications of the current are necessary.

S. Jellinek has written a monograph on death by electricity,[1] in which are found pictures of the gross and minute lesions occurring in the brain, cord, and different viscera.

Death from High-tension and Low-tension Currents.—High-tension currents cause death by respiratory paralysis, low-tension currents by cardiac paralysis, if they cause death at all. This is true in general, but, of course, a current which has a high voltage at the terminals of the dynamo may be so modified by the circumstances surrounding the man who accidently receives it that only a fraction of that voltage is applied to his body, and the heart, not the respiration, is paralyzed.

Prévost and Battelli have made many observations upon death by electricity[2] and have found that animals in whom cardiac paralysis has been produced by low-tension electricity may be resuscitated by high-tension electricity. This was done in the case of a dog—one electrode in the mouth, the other in the rectum. A 50-volt alternating current was applied for three seconds and produced heart fluttering, a condition of feeble and rapid action of the heart, which is the way in which electricity paralyzes the heart and from which spontaneous recovery seems to be impossible. A few seconds later, however, the application of an alternating current of 4800 volts for two seconds caused a return to normal cardiac action, and the animal's life was saved. It does not seem a desirable experiment to try in the case of a human

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[1] "Electropathologie," published by Enke, Stuttgart, 1903.

[2] "Comptes rendus de l'Academie des Sciences," vol. cxxviii, cxxx; "Journal de Physiologie et de Pathologie generale," 1899, 1900; "Revue medicale de la Suisse Romande," 1899, 1900.

being, because of the probability of producing destructive lesions in the central nervous system from the passage of a current of such volume as the 4800-volt alternating current. Faradization of the pneumogastric nerve for brief periods is a means of applying a current of moderately high tension and of a quantity so small as not to be capable of producing pathologic effects.

Relation of Rapidity of Alternation to the Physiologic and Pathologic Effect of High-tension Currents.—Industrial currents usually have about fifty alternations a second, and this rate causes the greatest effect upon living organisms. The highest voltages at this rate of alternation are so dangerous that even an approach to the conductors should be effectively guarded against, 550 volts is often deadly and 90 to 115 volts occasionally so under exceptional circumstances.

Alternating discharges are dangerous in proportion to frequency up to 150 a second and become progressively less effective physiologically beyond that frequency. A very much more rapid rate of alternation renders the same or even higher voltages harmless; and even deprives the current of its property of producing sensation or muscular contraction. Tesla, Thomson, d'Arsonval, and others have performed experiments in which high-frequency and high potential currents are passed through the body in sufficient quantity to light a 16-candle-power incandescent lamp requiring a current of ½ ampere under ordinary conditions. These go to show that alternations above 5000 a second lose the ordinary effects of electric currents upon the living organism. And experiments by Prévost and Battelli with machines giving alternations all the way up to 1700 a second[1] show that the more rapid the rate of alternation, the higher is the voltage required to produce death or other pathologic results. Of course, "high-frequency currents" are of a transcendental order of frequency, consisting perhaps of millions of oscillations a second, forming a to-and-fro discharge between the coatings of a condenser in the course of which their electric charges are liberated and neutralized. This discharge and these oscillations do not take place directly through the patient's body, which forms only a shunt circuit for the discharge. The principal path afforded for the current in one type of high-frequency apparatus is through the short thick wire solenoid. And the fact that any appreciable current passes through the patient instead of all going through the other much better conducting path is due to the development of an impeding self-inductance in the latter.

High-frequency currents in the usual strength and with a good contact with the electrode produce physiologic effects which are often of therapeutic utility. They do not produce pathologic changes in the tissues. They cannot be regarded as dangerous to handle, since the only bad effect is from sparks. These cause quite a sharp sensation, and produce the ordinary reflex muscular contraction by which nature causes a limb to be withdrawn from any source of irritation, fire and the like, without waiting for the sensation of pain to reach the brain and a voluntary impulse to be transmitted to the muscles of the limb. These sparks produce whiteness and swelling of the skin followed by redness and blistering or ulceration of practically the nature of a burn if the sparks fall upon one spot for too long a time. The shock which may be received from accidental sparking is trivial and the effects upon

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[1] Quoted by Boruttau, but I don't find these figures in the original articles in the "Journal de Physiologie et de Pathologie," 1899.

the tissues just described are purely local, and require an application of a number of seconds at a single point. They are almost always produced purposely, as in destroying cutaneous growths.

High-frequency currents applied as a shower of sparks produce, as we have seen, quite a sharp reflex muscular contraction and marked tissue changes, and the same is true when the electrode is applied to a very small point on the surface of the body. The high frequency of the alternations is, therefore, not the only element in causing an absence of sensation or muscular contraction in a human body, through which they pass when large surfaces of contact are employed.

Condenser Discharges and Their Pathologic Effects.—Holding a Leyden jar by the outer coating in one hand, and then touching the knob connected with the inner coating with the other hand, one receives a spark and shock which is influenced by the capacity of the Leyden jar and the voltage to which it is charged. A sharp muscular contraction of the arms is produced by such an experiment, but no pathologic changes.

Experiments with larger condensers have shown that small animals may be killed by a single or by a small number of successive single condenser discharges. Priestley, in 1766, killed dogs by the discharge from a condenser with 6.5 square meters surface charged from a static machine, cats with 3.5 square meters, and rats with 0.6 square meter. Since that time various experiments and observations have been made by Fontana, Troostwyk and Kragenhoff, Tourdes and Bertin, Richardson, Lazzaretti and Albertoni, and by Dechambre. It is to be gathered from their observations that a sufficiently powerful discharge will kill small animals and that different lesions occur, such as ecchymosis of the pleura or edema of the lungs.

D'Arsonval made a report in 1887[1] in a study of the cause of death from the industrial use of electricity to the effect that a static discharge could cause death only when applied directly to the medulla and very sharply localized.

Prévost and Battelli[2] have reported a most elaborate series of experiments upon this subject.

Fig. 263 shows the arrangement of the apparatus, a 35-cm. Ruhmkorff coil being employed and a condenser of adjustable capacity. Each plate of the condenser was of glass 2 mm. thick, covered on each side by 48 square decimeters (800 square inches) of tin-foil, and having an uncovered border of glass 11 cm. (4½ inches) wide. There were 15 such plates, any number of which could be used as a single large condenser, the capacity being 0.16 microfarad for each plate.

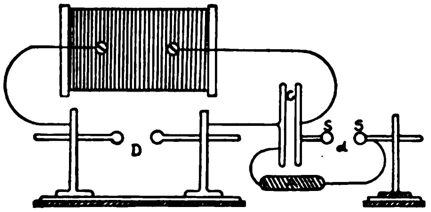

Fig. 263.—D, Spintremeter; C, condenser; d, explosive distance; A, animal; S S, metal spheres 2 cm. in diameter, one of which is movable (Prévost and Battelli).

The spintremeter or spark-gap (D) of the Ruhmkorff coil is set at a greater distance than the explosive distance (d), which determines the voltage of the discharge to be sent through the animal.

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[1] "Comptes rendue de l'Acadamie des science."

[2] "Journal de Physiologie et de Pathologie," vol. i, 1899, p. 114.

This is to prevent the discharge from taking place across the spintremeter and through the Ruhmkorff coil instead of through the animal.

The explosive distance (d), between metal balls 2 cm. in diameter, varies according to the voltage, as shown in the following table:

EXPLOSIVE DISTANCE.		DIFFERENCE OF POTENTIAL BETWEEN TWO SPHERIC CONDUCTORS OF A DIAMETER OF TWO CENTIMETERS (*Battelli*).
Centimeters.	*Inches.*	*Volts.*
0.02	0.008	1,530
0.04	0.016	2,430
0.10	0.040	4,800
0.20	0.080	7,400
0.30	0.120	11,400
0.40	0.160	14,400
0.50	0.200	17,100
0.60	0.240	19,800
0.70	0.280	22,500
0.80	0.320	24,900
0.90	0.360	27,300
1.00	0.390	29,100
1.20	0.480	33,000
MASSART AND JOUBERT.		
1	0.39	48,000
2	0.78	64,000
4	1.56	78,000

These figures are of the greatest interest, and much greater than the spark length of equal voltages where the two opposite charges are not bound together by a tremendous attraction and separated by only the thickness of a piece of glass, as in a condenser.

They indicate also that if an ordinary Leyden jar is charged to a potential of 33,000 volts and one end of the insulated discharging rod is applied to the outer coating, the discharge will occur when the other end of the rod is brought within 1.20 cm. of the knob connected with the inner coating.

The *quantity* of electricity contained in a charged condenser or given out when the condenser is discharged is $Q=CV$, the capacity multiplied by the voltage (C is expressed in microfarads, V in volts, and Q in microcoulombs).

The *work performed* in charging a condenser or performed by the discharge of a condenser is $W=\frac{1}{2}CV^2$ or a number of joules equal to one-half the capacity in microfarads multiplied by the square of the voltage. (One joule = 0.102 kilogram meter, or about 0.814 foot pound.)

The experiments of Prévost and Battelli show that the effect of a condenser discharge in causing death or other injuries to animals is proportional to the number of joules or to $\frac{1}{2}CV^2$, not to the quantity of electricity ($Q=CV$).

Accordingly, a single small Leyden jar charged to a certain voltage will not produce the same effect on an animal as a much larger Leyden jar or a large plate condenser charged to the same voltage. The quantity of electricity (27,132 microcoulombs) in a condenser of 2.38 microfarads capacity charged to a potential of 11,400 volts is greater than the quantity (15,510 microcoulombs) in a condenser of 0.47 microfarad capacity charged to 3300 volts potential. The energy or work (255 joules) in the smaller condenser charged to 33,000 volts is, on the contrary, greater than the energy (154 joules) in the larger condenser charged to 11,400 volts. Prévost and Battelli subjected a young rabbit weighing 1040 grams to a single discharge under the above conditions of small quantity (15,510 microcoulombs, but large energy—225 joules), and the symptoms produced were arrest of respiration, cardiac fibrillation, and death. Another young rabbit weighing 1020 grams was subjected to a single discharge under the other conditions of large quantity (27,132 microcoulombs) and small energy (155 joules), in which case breathing gradually commenced again and the animal survived.

Fastening the animal upon an insulated table, one metal electrode was placed in the mouth and the other in the rectum. The polarity was found not to make any difference.

The size of the animal determines the electric energy as a single condenser discharge required to produce permanent arrest of respiration and death. The most powerful discharge from their 15-plate condenser (800 square inches in each of the two sets of metal coatings charged to a potential of 33,000 volts) failed to kill dogs weighing 6500, 7000, and 8500 grams (14.3, 15.4, and 18.7 pounds). The electric energy applied in the condenser discharges were either 1029 or 947 joules, and the dogs exhibited no symptoms beyond slight temporary changes in blood-pressure.

Rabbits weighing about 2000 grams (4.4 pounds) required 900 or 1000 joules to produce a fatal result. For instance, a single discharge from a condenser of 1.27 microfarads capacity, charged to a potential of 29,100 volts, and possessing, therefore, an energy of 549 joules, produced clonic convulsions, temporary impairment of respiration; the heart beat normally and the animal recovered. Another rabbit subjected to a single discharge from a condenser of 2.38 microfarads capacity charged to a potential of 29,100 volts, and possessing, therefore, an energy of 1029 joules, showed no convulsions, the heart beat feebly, respiration was abolished, and the animal died.

Young rabbits weighing about 1200 grams required about 300 joules, and guinea-pigs weighing about 250 grams required about 130 joules, and those weighing 450 grams about 400 joules to arrest permanently the respiration and kill the animal.

Young animals in general are more susceptible than adult animals.

Beyond a certain voltage represented by an explosive distance of about 1.5 cm. ($\frac{6}{10}$ inch), more powerful results are better obtained by increasing the size of the condenser and, therefore, its capacity rather than by increasing the potential or voltage as represented by the explosive distance.

The effects of condenser discharges upon animals are proportional to the number of joules (the number of microcoulombs multiplied by the square of the number of volts), and inversely proportional to the size of the animal. A number of successive discharges will produce a cumulative effect, but not so great as the same total of electric energy in a single more powerful discharge.

The pathologic effect of a number of condenser discharges in rapid succession. An adult rabbit which would be killed as if by lightning by a single condenser discharge of 947 joules (from a condenser of 1.74 microfarads capacity, charged to a potential of 33,000 volts), will survive two discharges of 517 joules (from a condenser of 0.95 microfarad capacity charged to 33,000 volts) applied thirty seconds apart. After the first discharge there were clonic convulsions; respiration and cardiac action were not arrested. After the second discharge there were no convulsions; respiration continued; reflexes were absent, and there was great inhibition of all nervous functions. Recovery took place gradually.

Several different degrees of effect are recognized by Prévost and Battelli:

1. A single general muscular contraction.
2. Clonic convulsions without much effect on respiration, and rapid recovery.
3. Tonic convulsions, momentary arrest of thoracic respiration.
4. General inhibition of the nervous system, no convulsions, loss of reflexes; absolute arrest of thoracic respiration. The auricles of the heart are often arrested.
5. Complete arrest of the heart: loss of excitability in the unstriped muscle of the intestine; preservation of the excitability of the striated muscles and of the motor nerves.

The blood-pressure varies according to the severity of the effect. In Prévost and Battelli's first degree of effect the blood-pressure becomes slightly higher after a momentary fall; in the second, third, and fourth degrees it generally rises abruptly and remains elevated. In the third and fourth degrees there is sometimes a fall of blood-pressure, due to fibrillary tremor of the ventricles, which is temporary in these degrees. In the fifth degree the heart is unable to reëstablish normal pulsations, the fibrillary tremor continues changing to complete arrest, and the fall in blood-pressure is permanent. There is abolition of the excitability of the unstriped muscular fibers supplied by the sympathetic nerves.

The pathologic lesions are slight, such as congestion with pulmonary edema and subpleural ecchymoses. Rigor mortis is pronounced and develops early.

Pathologic Effect of Alternating Currents.—Prévost and Battelli,[1] in studying the different effects of alternating currents on dogs, cats, guinea-pigs, rabbits, and rats, found that the effect of these currents upon the heart was functional dissociation of its movement and production and suppression of fibrillary tremor. The same authors, in studying the method of death by *continuous currents*, March 27, 1899, found that when a sufficiently strong current was applied, a dog was killed by paralysis of the heart, fibrillary tremor, while a guinea-pig or rat died from paralysis of respiration. The rabbit presents momentarily a condition of fibrillary tremor of the heart, and then a temporary slowing of respiration which reëstablishes itself gradually. The maximum potential applied in these experiments was 550 volts. Alternating currents of low tension, up to 120 volts, produced in the animals experimented upon by Prévost and Battelli (dogs, rabbits, guinea-pigs, and rats) only slight nervous symptoms. The respiration was only temporarily affected, and the same was true of general sensory conditions. A tension of 20 volts with an electrode placed on the head produces a generalized tetanus with opisthotonos, which is often followed by chronic convulsions. When neither of the electrodes is placed on the head, it requires at least 60 volts. When the electrodes are applied to the anterior limbs, the ventricles of the heart present fibrillary tremor, while the auricles continue to beat. This is the same result that is

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[1] C. R. Ac. des Sci., March, 3, 1899.

obtained by direct electrization with an induced current. This is always fatal in dogs, as the heart does not seem to be able to resume its normal function. The same is true of adult guinea-pigs, weighing at least 400 grams. The rabbit hardly ever dies, because the heart most frequently resumes its rhythm. The rat never dies, because the tremors cease as soon as the electrization is stopped. In dogs and guinea-pigs respiratory movements continue for a long time, in spite of the paralysis of the heart. In this case artificial respiration could not be of any service. To produce the fibrillary tremor of the heart requires a contact of at least a second with the electrodes placed upon the head and thighs, or even over the precordial region. Preliminary section of the pneumogastric nerves has no influence over the phenomena of fibrillary tremor of the ventricles. "Death by high-tension alternating currents from 1200 to 4800 volts, applied to the head and feet, is not due to fibrillary tremor of the ventricles of the heart, as in the case of low-tension currents. They provoke in all the animals grave troubles of the central nervous system and arrest of respiration, loss of sensibility, profound prostration, generalized tetanus, loss of reflexes." Death is due to respiratory paralysis, the arterial tension undergoing considerable elevation, and the ventricles beating rapidly and energetically, while the auricles are arrested in diastole. If the respiratory paralysis is permanent, the heart gradually fails.

Currents of medium voltage, 240 to 600 volts, applied to the head and feet, produce in the rat, the guinea-pig, and the rabbit nervous troubles, but less grave than those produced with a current of high tension. The heart does not present fibrillary tremor except in the rabbit. In the dog, however, fibrillary tremor occurs and death ensues from simultaneous cardiac and respiratory paralysis.

Death from the Action of Continuous Electric Currents.—The electrodes are placed one in the mouth and the other in the rectum or upon the thighs. The positive electrode is most often placed in the mouth, but the polarity does not make any difference. The symptoms are the same whether the current is produced by dynamos or by batteries. Dogs die from paralysis of the heart with a voltage of from 50 to 70, at the least, while respiration continues for several minutes longer. The ventricles present fibrillary tremors while the auricles continue to beat. It was consequently useless to practise artificial respiration. With the highest voltages employed, 550 volts, the heart was arrested by a single shock, opening and closing of the circuit. Respiration was suspended for several seconds and then recommenced, but feebly and slowly failed. In guinea-pigs fibrillary tremor of the heart was produced by a tension of 100 volts, but the heart was not completely arrested with less than 200 or 300 volts. A voltage of 550, on the other hand, seldom paralyzes the heart. Rabbits seldom die from cardiac paralysis, the condition of fibrillary tremor being only temporary. The same is true of rats. In all the animals experimented upon, currents of 550 volts caused arrest of the auricles in diastole, this condition continuing for one or two minutes. The higher the voltage, the more pronounced are the effects upon the nervous system, except in the case of convulsions, which are produced when the voltage is about 50, and do not occur when the potential is raised to 550 volts, and the duration of contact prolonged for two or three seconds, for example.

D'Arsonval, having stated[1] that the only danger from continuous currents lay in the shock occurring when the current was made and broken, Prévost and Battelli[2] made experiments to determine the facts. Using a direct dynamo current of 550 volts, and having a liquid rheostat of 15,000 ohms resistance in series with the animal experimented upon, the current was turned on and off a number of times without effect of any kind upon the animal. The enormous resistance of the rheostat enables one to turn the current on and off without exciting muscular contraction or any other symptom. After turning the current on, the resistance may be gradually diminished and the current increased to any desired strength without a "make" shock. It has been proved in this way that fibrillary tremor of the ventricles of the heart may be produced without any "make" shock. The gravity of the functional disturbances of the nervous system is also not appreciably modified by the absence of the "make" shock.

The Effect of the Presence or Absence of the "Break" Shock.—Fibrillary tremor of the ventricles of the heart may occur without the "break" shock, and may continue and be the cause of death after the strength of the current is gradually reduced to zero by the rheostat, the occurrence of the "break" shock being entirely prevented. With low-tension currents, however, which are not strong enough to cause fibrillary tremor without the "make" and "break" shocks, these tremors and the resulting cardiac paralysis and death may be produced by a break shock. This would be done by turning off the current abruptly from its full strength instead of gradually reducing it by means of a rheostat. The "break" shock from a current of 80 volts or even 50 volts applied in this way will kill a dog by fibrillary tremor of the ventricles of the heart.

Action of the Shocks of Opening and Closing the Circuit.—With a high enough tension, 100 volts in the case of guinea-pigs, neither the opening nor closing shock is necessary in order to produce fibrillary tremor of the heart, but with comparatively low voltages, 70 volts, in the case of dogs, the heart continues to beat during the passage of the current, while the fibrillary tremor is produced by the shock of breaking the current. With currents of high tension, 450 to 550 volts, the ventricles of a guinea-pig which had been in a state of fibrillary tremor during the passage of the current are caused to recommence normal contraction by the shock of breaking the current, but if one avoids this shock, by gradually reducing the strength of the current to 0, the paralysis of the heart remains permanent. In the dog, on the other hand, the shock of breaking the current does not reëstablish the beatings of the heart, and Prévost and Battelli regard it as probable that the shock from the 550-volt current was not sufficient to produce that effect. The shocks of making and breaking do not appear to have a very marked influence upon the occurrence of troubles of the nervous centers, but in case of a current of low tension, the condition of generalized tetanus is provoked by the shock of breaking the current.

Absence of Pathologic Effects from Leyden Jar and other Condenser Discharges in the use of Electrotherapeutic Apparatus.—The condensers used in high-frequency apparatus in connection

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[1] C. R. de l'Acad. des Sciences, April 4, 1887.

[2] Journal de Pathologie et de Physiologie, 1899.

either with a static machine, or an induction coil, or an alternating current transformer (D'Arsonval-Gaiffe apparatus) are of small size compared with those found necessary to produce pathologic results in animals, and their effect is still further reduced by the greater size of men. Only the smallest animals are seriously affected by powerful condenser discharges. The single muscular contraction with slight increase in blood-pressure, which are the effects produced upon men by the discharge of any of the condensers used in electrotherapy, can hardly be regarded as pathologic. There is no danger of serious results in handling this part of the apparatus.

History of Death from Electricity.—Grange[1] was the first to report two deaths from dynamo currents. He also experimented upon animals, and considered that minute hemorrhages in the medulla caused respiratory paralysis and death.

D'Arsonval's article in 1887 was largely theoretic. He stated that the discharge from a static machine acted as a local disruptive agent and permanently destroyed the tissues affected by it. This would be the case also with lightning-stroke. Dynamo currents, he thought, acted in a reflex inhibitory manner upon the nervous centers, and this inhibition might be received from them. Death would be attributed to respiratory paralysis, and the proper treatment would be artificial respiration. This will be found to correspond very closely with the most recent knowledge of the subject.

Brown, Kennelly, and Peterson[2] reported experiments upon one horse, two calves, and a number of dogs. Copper wire wrapped with wet cotton was wound around one fore leg and the opposite hind leg of the animal. An alternating current of 160 to 800 volts turned on for a second always caused instant death. A continuous current of the same strength and for the same length of time was not always fatal. The usual number of alternations was 34 a second, and if this was increased to 100 or 134 periods a second, death was caused by a current of lower voltage.

Tatum[3] reported experiments upon animals in which death was caused by respiratory paralysis. This occurred even when a preliminary section of the vagus had been performed, and also in atropinized animals.

Electrocution was adopted in New York State in 1890. An alternating current of 1500 volts and from 15 to 30 periods a second is used. Several seconds' contact abolishes all sensibility, but the heart continues to beat and respiration will reëstablish itself unless one or two more additional shocks are given.

McDonald[4] reports the result of autopsies upon several persons who had been electrocuted. Capillary hemorrhages were found in the floor of the fourth ventricle and in the third ventricle, but they were not constant.

Biraud[5] made three experiments on rabbits with an alternating current of 2500 volts. It took twelve seconds to stop the beating of the heart.

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[1] Annales d'hygiene et de medicine legale, 1885, pp. 53 and 303.

[2] N. Y. Med. Jour., 1889.

[3] Ibid., 1890.

[4] Ibid., May 14, 1892.

[5] Thèse de Lyon, 1892.

Philip Donlin[1] believed that the current produced an alteration in the blood which caused secondary changes in the nervous system. (Battelli states that these changes in the blood have not been confirmed by any other observer.)

Kratter[2] experimented upon numerous animals of different species, using an alternating current. He concluded that death was due to paralysis of the respiratory center, the heart's action failing gradually. Different animals vary in susceptibility. Guinea-pigs and rabbits are less susceptible than dogs. He submitted rats to a current of 100 volts, and it required thirty seconds' contact to kill them. All the other animals were subjected to currents of higher tension. He did not find any constant lesions, either gross or microscopic, the blood and the cells of the nervous system were unchanged.

Oliver and Bolan[3] experimented upon dogs and rabbits with currents of 200 volts. There was immediate arrest of the heart, while respiration continued until it gradually failed. They thought that the effect upon the heart was a direct one, as it occurred just the same when the pneumogastric was divided. The electrodes employed were moistened sponges which were applied to the front and hind legs, which had previously been shaved. They tried to re-animate the paralyzed heart by various methods, but unsuccessfully.

Corrado[4] applied continuous currents of high tension to dogs. The animals died immediately, even from very short contacts, and both heart and respiration seemed to be instantly paralyzed.

(All the above observations are quoted more or less in extenso in Prévost and Battelli's excellent monograph upon Death by Electricity.)

Battelli[5] has made the experimental study upon which most of our exact knowledge of the subject is based. The *electrodes* for application to the skin were made of copper or zinc, covered with moistened cotton. The skin was shaved and the electrode bandaged in place. The mouth electrodes, for dogs, consisted of two copper plates placed in the fold between the gums and the cheek. Rectal electrodes were made of brass.

The source of current was the alternating electric-light circuit, the three-wire system, with 240 volts difference in potential between the neutral wire and either of the others. This current was modified by a closed magnetic circuit transformer, giving voltages of 600, 1200, 1800, 2400, 3600, or 4800. These figures represent the effective voltage, which is 1/1.42 the maximum voltage, this formula being true of sinusoidal currents in general. To use a current of less than 120 volts, a spiral rheostat with a resistance of 10 ohms is introduced into the circuit, and any two turns are connected with the electrodes. Electric measurements are made during the experiment by means of the voltmeter, the amperemeter, or milliamperemeter, and Kohlrausch's telephonic bridge to measure the resistance of the body. Sometimes the contact was as short as one-twentieth of a second, and then the amperemeter or milliamperemeter would not register; but the strength of the current could be calculated from the voltage and the electric resistance of the animal's body.

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[1] Medicolegal Society of New York, November 10, 1889.

[2] Der Tod-durch Electricität, Leipzig, 1896.

[3] British Medical Journal, January 15, 1898.

[4] Archives d'Electricite medicale, 1899, p. 5, No. 75.

[5] Journal de Physiol. et de Pathol. Gen., 1899.

Destructive Electrolysis.—An electrolytic needle thrust into an organ like the kidney, testis, or brain destroys the microscopic structure of the organ.

Pathologic Effect of Electricity Upon the Blood.—Under the influence of a powerful electric current Rollet has observed a dissolving out of the hemoglobin in the red blood-cells, the blood becoming transparent and consisting of a clear red liquid in which are suspended colorless and perfectly transparent blood-cells. This has been questioned by Herman and Cremer, and must still be considered as unsettled.

Accidents from Electric-lighting and Power Currents.—Fatal accidents have occurred with alternating currents of as low as 100 volts.

As to the amount of these currents passing through the body, absolute safety requires that it should not exceed 25 ma.; 30 ma. is often dangerous, and 100 ma. is almost always fatal.

The resistance of the human body to the direct current is about 50,000 ohms when a bare wire is touched by a finger-tip, and 600 ohms when a conductor is held in the hand. The same figures are 15,000 ohms and 200 ohms for the alternating current.

Rubber gloves are a most uncertain protection.[1]

A case of accident from contact with a live wire is recorded by N. Jacobson.[2] The patient was a boy twelve years old who took hold of a bare wire carrying a current of 6600 volts and 90 amperes with his left hand, while it is supposed that his left foot touched the companion wire, so that the current was short circuited through his body. There was not exactly a burn, but there ensued an impairment of arterial supply, either from thrombosis or vasomotor contraction, and moist gangrene set in. The arm and leg had to be amputated fifteen days after the injury. There were no special symptoms of constitutional or visceral disturbance, and the boy recovered.

The wires were carrying a current of four times as many volts, and from fifteen to forty-five times as many amperes, as are required for the electrocution of criminals. There is this great difference, however, that in the case of the criminal care is taken to make a large and perfect contact between the shaved and moistened skin of the person and unoxidized surfaces of the metallic conductors, while in this accidental case the wire was exposed to the weather and its surface presumably oxidized and a poor conductor. The area of contact when a wire is grasped by a boy's hand is small, and when simply touched by a boy's foot, is still smaller. Add to this the resistance of the boy's shoe and stocking and the possibility that his foot did not come in contact with the wire, but was merely grounded, and it is easy to see that the resistance was so great that a tension of 6600 would send a very much weaker current through the boy's body than the 90 amperes which it sends through the complete system of conducting wires to which it is designed to supply current.

Cases treated by the present author include one in which a telegraph lineman was injured by grasping a telegraph wire which had become charged with the 500-volt trolley current. This happened in midair, and as he hung there unconscious the wire burned deeply into the palm of the hand. After a few minutes he fell to the ground and fractured his femur. He made a good recovery. Another case was that of a

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[1] Report of M. Zacon, labor inspector at Cambrai, Hygiene gen. et appliqué, January, 1906.

[2] Buffalo Medical Journal, January, 1907.

man injured while working upon the charged wire in the slot of the buried trolley wire. There had been a blinding flash as his hand touched the wire, and the skin of the hand and wrist was singed and blackened. There was a marked reduction in motor power in the hand, and this took longer to cure than the burn.

Burns in Electrotherapy.—The burn which may be inflicted by the flow of a current of 20 ma. for four seconds, as may happen if too strong a current is used in Fort's method of linear electrolysis, is certainly not due to the heating effect of the current. Experiments by Lauret and Bellocq[1] show that the elevation of temperature for the entire surface of contact between the uninsulated part of the electrode and the flesh would be only about 2° F. This rise of temperature is not enough to redden the mucous membrane or to produce any uncomfortable sensation.

A similar state of things is found when one comes to measure the amount of an acid or base set free at the surface of the skin by electrolysis of the liquid which is used to moisten the electrode. In one experiment by Lauret and Bellocq an electrode moistened with a 1:1000 solution of caustic potash produced a burning sensation upon the operator's forearm which could hardly be borne with a current of 2 ma. applied for two or three seconds. A calculation shows that only $\frac{7}{1000}$ milligram of potash was set free, not enough in an ordinary chemic manner to produce any perceptible effect upon the skin. The effect differs with the solutions employed and the exact arrangement. Some of their other experiments upon their own forearms were as follows:

One electrode consists of a little glass cylinder, open top and bottom, which, when applied to the skin, can be filled with a liquid. The bottom is formed by the patient's skin, and a wire passes into the liquid through a cork at the top. Another electrode consists of a porous earthenware jar full of liquid into which a wire dips and the bottom of which transmits enough moisture to make a good contact with the skin. The indifferent electrode is always a large flat one covered with moist chamois.

First Experiment.—Large indifferent positive pole at upper part of arm. Negative carbon electrode of ordinary size covered with moist chamois. A current of 15 or 16 ma. was required to produce the burning sensation described above. Reversing the current, 20 ma. were required.

Second Experiment.—The glass cylinder full of tepid water was used for the active electrode, and 10 ma. produced the same burning.

Third Experiment.—The glass cylinder full of a tepid $\frac{1}{1000}$ solution of sulphuric acid was used as the active electrode, and the same burning required only 2 ma.

Fourth Experiment.—The glass cylinder full of $\frac{1}{1000}$ solution of caustic potash was used as the active electrode, and the same burning occurred with a current of 3 ma.

Fifth Experiment.—The same acidulated solution was placed in the porous jar and used as the active electrode. A current of 8 ma. produced the same burning sensation.

In all the above cases a reversal of the polarity made scarcely any difference.

Burns from currents of electrotherapeutic strength are usually due to ionization.

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[1] Annales medico-chirurgicales du Centre, May 15, 1905.

ELECTRODES

MATERIALS FOR ELECTRODES

ELECTRODES FOR SURFACE APPLICATION

Electrodes for Application to the Skin.—Electrodes for the application of the faradic current to the surface of the skin may consist of metal cylinders to be held in the hand, or metal plates for the feet to rest upon, because the current strength in milliamperes is very small and the current is alternating. Both these characteristics tend to prevent changes in the skin as the result of contact with the metal. It also makes little difference what metal is employed.

Metallic electrodes may also be used for the application of static electricity and high-frequency currents of either high or low potential. The small amperage in the first case and the alternating character of the discharge in the case of high-frequency currents prevent electrolytic effect. Providing the electrode is in good contact and is of sufficient size, no effect is produced upon the skin at the place of contact.

The conditions are quite different when the galvanic current is used, and especially when strong applications of it are made. The current is continuous and unidirectional, and has the strongest tendency to produce electrolytic effects in the tissues, even with platinum electrodes, which undergo practically no change themselves. Additional changes are produced when copper, iron, or other corrodible metals are used as electrodes.

The Difference in Potential Between the Electrode and the Skin.—The general principles for the prevention of these changes, known collectively as *burns*, are that the current density must not be too great,—perhaps not more than ½ ma. per square cm.,—and that the difference in potential between the skin and the electrode must not be too great. If the difference in potential is too great, changes are produced in the skin which one or two examples from ordinary physical processes may illustrate. In electric lighting there is a difference in potential between the two wires of, say, 110 volts, and if these wires are allowed to touch each other, there is a blinding flash, and the metal is melted, vaporized, and burnt up; there is also the danger of setting fire to the building. This effect continues until the current is turned off, perhaps automatically, by the burning out of a fuse. Contrast this with the effect produced by crossing two bare wires connected with the poles of a single galvanic cell, and, therefore, having a difference of only $1\frac{75}{100}$ volts in potential. There is a tiny spark when the contact is broken, but no visible effect while the wires actually touch each other and the difference in potential is reduced to zero.

In the *Wehnelt interrupter* the two wires have a difference in potential of almost 110 volts before contact is made with the liquid, and a difference of about 80 volts remains even when the electrodes are immersed. The difference in potential between the platinum point and the liquid with which it is in contact is so great that the passage of the current from the platinum point to the liquid is accompanied by vaporization and incandescence of the liquid, so as to form a luminous sphere around the platinum point, and momentarily break the contact with the liquid and interrupt the flow of the current.

The effect in the Wehnelt interrupter is never exactly duplicated in the application of currents of the proper intensity for therapeutic use. The flesh is never vaporized and ignited, but when heavy therapeutic currents are used, contact with a small metallic electrode will produce electrolytic effects, causing pain and perhaps even blistering or destruction of the skin.

Such effects are obviated to a great extent by having the current enter the body through the intermediary of some substance having about the same resistance as the body. There is then only a slight difference in potential between the skin and the substance in contact with it. A sponge wet with a solution of sodium bicarbonate may be used to cover the surface of a metal disk connected with one pole of the battery (Fig. 264). The patient's body and the solution then form a continuous electrolyte, and the changes due to electrolysis take place practically entirely at the surface of contact between the metal and the solution of sodium bicarbonate. It is there that there is a great increase in the resistance encountered by the current, and it is there that the electromotive force of the battery maintains a great difference in potential. The effect of electrolysis at that point is seen in the corrosion of the metal and in a dissociation which chemic analysis would show to have occurred in the solution.

Fig. 264.—Sponge electrode and insulated handle.

All the different electrodes for external use, covered with moistened sponge, felt, chamois skin, cloth, clay or kaolin, are based upon this principle.

They all possess another advantage over metal electrodes for external use in the fact that the moistened material makes a much larger surface of contact with all the interstices of the skin. The current is supposed to be largely transmitted through the sweat-glands, most of the other parts of the skin being highly resistant to the passage of a current.

Cases occur, however, in which the effect of the direct external application of a metallic electrode is desired. The treatment of ulcers by zinc ionization is an example. The active positive electrode is of zinc, and is applied directly to the ulcerated surface, and the caustic effect of the liberated zinc ions is beneficial in some cases.

Clay Electrodes.—Ordinary modeling clay in a moist soft condition may be used to secure a uniform resistance at all points of contact with the skin, and, what is equally important, a contact without too great a difference in potential.

The clay is shaped into a disk of the proper size, and about ½ inch thick, and a sheet of metal about one inch less in diameter is placed on the side away from the patient and fastened to one of the conducting cords.

Clay electrodes may be used for the indifferent electrode when heavy currents are employed, as for the destruction of cancers by electrolysis or cataphoresis, and for both the indifferent and the active electrode when heavy currents are used in the treatment of neuralgia.

They are much less desirable than kaolin electrodes from the standpoint of cleanliness.

Kaolin Electrodes.—This material, from which some kinds of porcelain are made, should be purchased in powdered form, and sewed up in flat bags of crash toweling, so as to make a pad 1 inch thick, and of different sizes, such as 8 by 12 inches and 14 by 20 inches. The latter are for the indifferent electrode when the heaviest currents are used. The kaolin pads are kept in water, and may be sterilized by boiling if they are to be used more than once. The largest sized pad will transmit a current of 500 ma. without burning if placed under the patient's back. A piece of flexible sheet metal, of the kind known as *x*-ray foil, 2 inches less in each diameter, is laid smoothly over the side of the pad away from the patient. A No. 26 insulated copper wire from one pole of the battery or other electric generator has its end bared and passed through perforations in one corner of the sheet metal, which is then wrapped around and securely pinched to the wire. It is wise to put a piece of rubber-coated cloth between the bared wire and the kaolin pad.

Kaolin pads of suitable sizes and shapes are also useful when a heavy current is to be passed through the knee-joint.

Carbon electrodes covered with chamois and frequently rinsed in pure water to remove electrolytic products may be used on the delicate skin of children.

Electrodes for Application to Mucous Membranes.—There are several reasons why these are usually made of metal. They are not required to transmit the very heavy currents for which large kaolin pads are useful. They are used chiefly for currents intended to produce a local effect, which varies in different cases from a mere stimulation to electrolytic and even caustic action. The moisture upon the surface of the mucous membrane often takes the place of the moistened sponge or kaolin pad used for external applications in preventing electrolysis of the tissues. This is true, however, only for the weakest currents. A rectal electrode causes pain with a current of 5 ma., and a small electrode applied to the gums produces pain and frothing from gaseous evolution in the tissues with a current of 1 or 2 ma. Electrolysis of the tissues of


Fig. 265.—Apostoli's bipolar vaginal electrode.

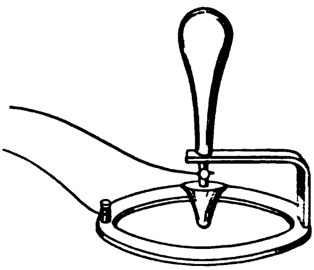
Fig. 266.—Bipolar cutaneous electrode.

a mucous membrane without the influence of ions from the metal electrode is obtained by the use of platinum electrodes. The influence of metallic ions is sometimes desired, as in treatment of fissure of the anus, where a copper positive electrode may be used.

Bipolar Electrodes.—These are sometimes used, especially in the uterus or urethra (Fig. 265). The two conducting cords from the battery pass to two metallic terminals in an insulated stem of hard rubber, through which wires lead to two metal bands surrounding the stem. These have an insulated space of ½ inch or more between them. The effect of the current is quite local, there being practically no general diffusion.

Another form of bipolar electrode (Fig. 266) is suitable for *external* use. One terminal is a point in the middle of a ring which forms the other terminal. They are ½ inch apart.

Bipolar electrodes are also made for *galvanopuncture.*

ELECTRODES FOR GALVANOPUNCTURE

A fine needle of platinum or, preferably, iridoplatinum is held in an insulated handle as the negative electrode for the electrolytic destruction of superfluous hair (Fig. 267). A fine steel needle with some flexibility, like a dental broach, may be used for the same purpose, and if so, it is especially important that it should be connected with the negative wire, because of the iron staining of the tissues which would result if it were the positive electrode.

Needle electrodes for the destruction of vascular and other nevi, and of tumors, and for the cure of aneurysms, often have an insulating coating of collodion or varnish to prevent action upon the skin and limit it to the deeper tissues surrounding the point of the needle.

Galvanocautery Blades.—These (Fig. 268) are not really electrodes, but rather parts of a complete circuit where the resistance to the flow of the current is so great that the conducting material becomes red hot or white hot. Platinum is the usual material for this purpose, and a strip is used which is very thin and narrow when only a few galvanic cells are to be used, as in most operations on the nose and throat, but broad and heavy, though only so by comparison, when currents of 50 amperes or more are employed in such operations as Bottini's, upon the prostate gland. In some cases the platinum is wound about a porcelain point, giving an increased surface.

Fig. 267.—Needle and handle for galvanopuncture.

Brush Electrodes.—These are made of fine brass wire, and are used for the application of faradic currents by rubbing the flexible brush lightly over the surface (Fig. 269).

Roller Electrodes.—Metallic cylinders may be rolled over the surface in certain applications, particularly of galvanic and static electricity. The roller may be monopolar or bipolar (Figs. 270 and 271).

Glass Vacuum Electrodes.—These are made the subject of special paragraphs at p. 483.

Condenser Electrodes.—These also are specially considered (p. 482).

Electrode Handles.—These have an insulated grip of wood or hard rubber and a metallic section, into which one of the conducting cords from the battery may be fastened by means of a thumb-screw. The electrode may be screwed onto this section, as in the non-interrupting electrode handle (Fig. 272), or an insulated section may intervene, and the electric connection between the conducting cord and the electrode may be made and broken by a Morse key, which forms part of the handle (Fig. 273).

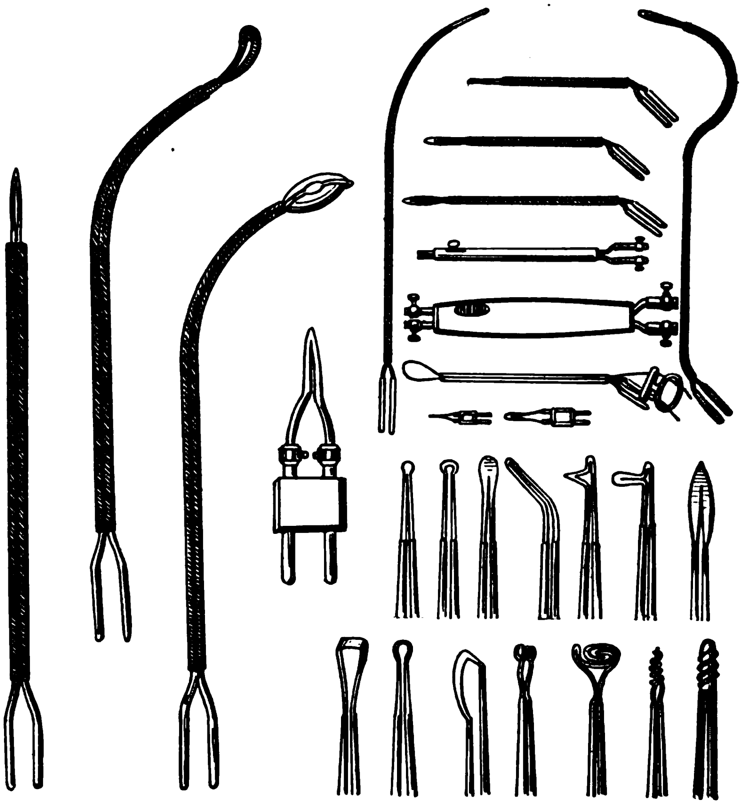

Fig. 268.—Cautery handle and assortment of blades.

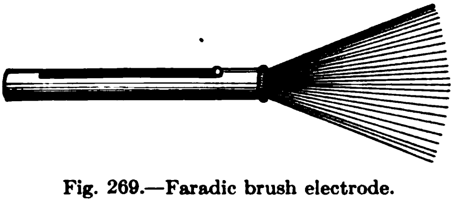

Fig. 269.—Faradic brush electrode.

Intragastric Electrodes.—These are metallic electrodes with an insulated stem which may be so flexible that the patient is required to swallow the electrode (Einhorn), or so stiff that it may be used to push the electrode into the stomach (Boas), or there may be a flexible insulated stem and an additional stiffer one used for introducing the electrode, but removed later.[1]

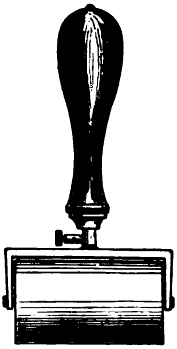

Fig. 270.—Multipolar faradic roller electrode.

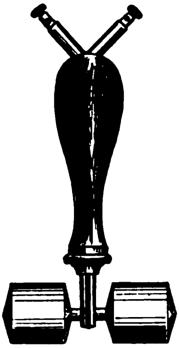

Fig. 271.—Bipolar faradic roller electrode.

Fig. 272.—Non-interrupting handle for electrodes.

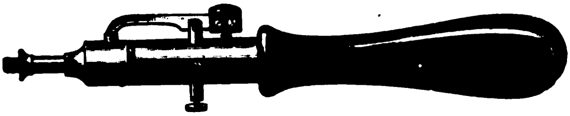

Fig. 273.—Interrupting handle for electrodes.

In every case the metallic electrodes should be protected from direct contact with the gastric mucous membrane by being enclosed in a perforated shell of hard rubber.

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[1] Bassler, Jour. Am. Med. Assoc., May 2, 1908.

ELECTRODIAGNOSIS

This consists chiefly in determining the effect of electric stimulation of nerves and muscles, and of some special organs, and in determining the electric resistance of the body.

The Electrodes.—The active one has a surface of 3 square centimeters, and is usually applied at the motor point of the muscle or nerve. The other electrode is larger and is usually applied at some indifferent part of the body. They are both thoroughly wet with a solution of sodium chlorid or of sodium bicarbonate.

Normal Electric Reactions.—The faradic excitability is more or less empirically determined by comparison with the similar adjustment of the apparatus to produce muscular contraction in persons whose muscles and nerves are in a normal condition.

The galvanic excitability should be such that in most regions with the active electrode applied at the motor point of a muscle contraction takes place at the cathodal closure with ½ to 1 ma.; at the anodal closure, with 1 to 2 ma.; at the anodal opening, with 2 to 2½ ma.; and at the anodal closure, with 15 ma. The amplitude of these different contractions with the same strength of current is expressed by the

Normal formula:

Ca Cl C>An Cl C>An O C>Ca OC.

(The radial nerve and sometimes the median and peroneal give a slightly different normal formula, CaCl C>An OC>AnClC>CaOC.)

Pflüger's Laws.—*Weak currents* give only a closure contraction; *medium currents* give opening and closure contractions; *very strong currents* in the direction of nerve conduction give only closure contractions, and in the reverse direction only opening contractions.

Motor Points.—The illustrations (Plates 1–8) show the positions at which the active electrode should be placed in order to produce the most effective stimulation of the muscle or motor nerve in question. They are based partly upon the studies of Erb, Castex, and Schatzki, and partly upon personal observations.

Some Special Motor Points.—The *trunk of the facial nerve* may be stimulated by means of a small electrode in the external auditory meatus pressing forward and upward.

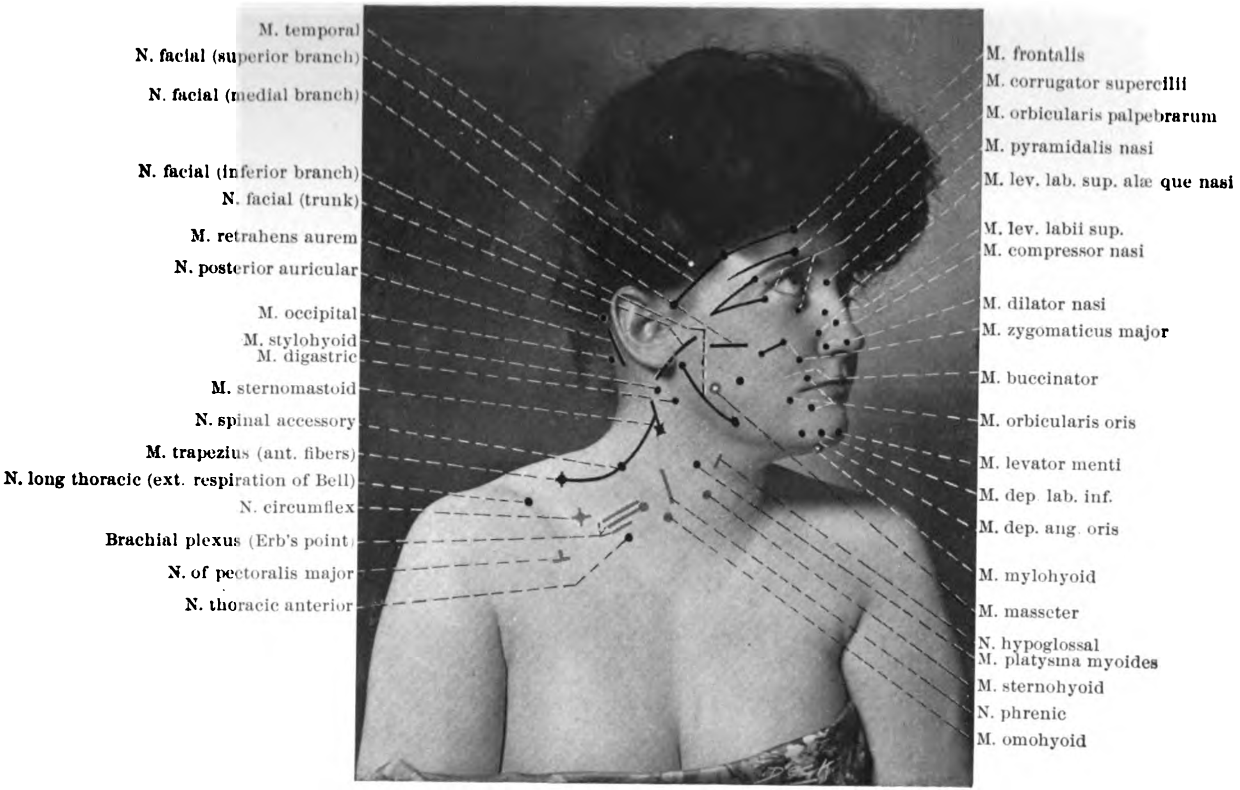
The *phrenic nerve* may be stimulated with a very small electrode placed on the posterior border of the sternomastoid muscle. It produces a sudden inspiration, with protrusion of the abdomen and a sound as the air passes through the larynx.

Erb's point is in the supraclavicular fossa, and its stimulation produces simultaneous contraction of the deltoid, biceps, brachialis anticus, and supinator longus.

The *median nerve* may be stimulated in the axilla, at the bend of the elbow, or at the wrist, between the flexor tendons.

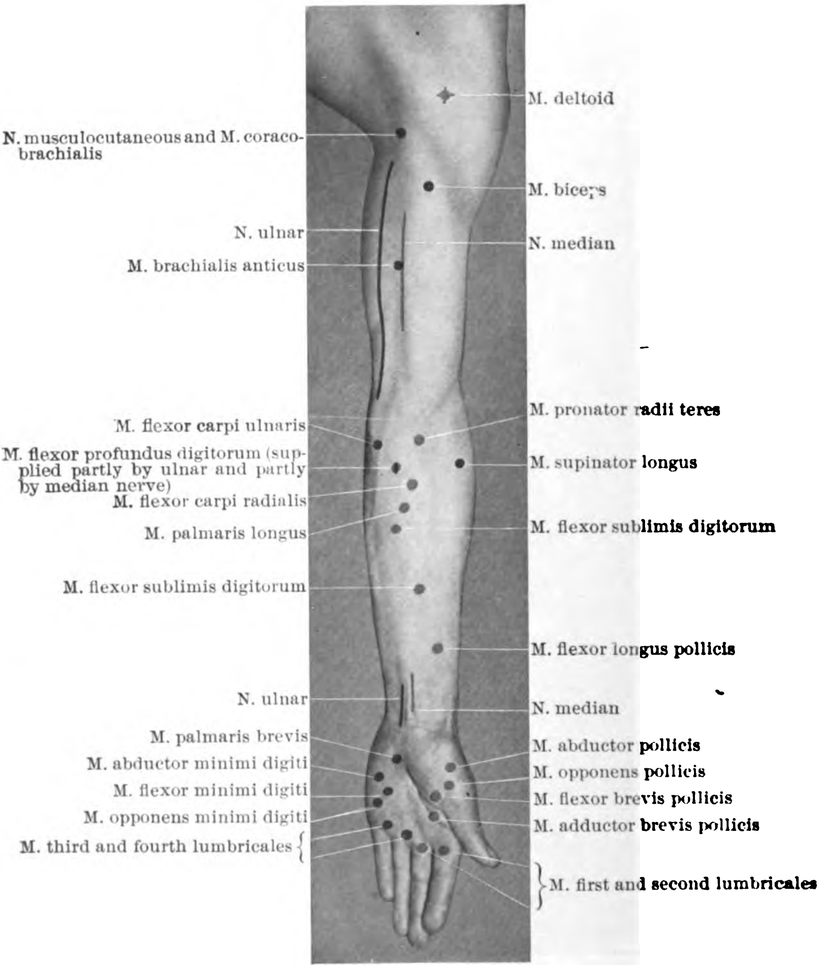
Electric Resistance of the Body.—It is generally a little higher

PLATE I



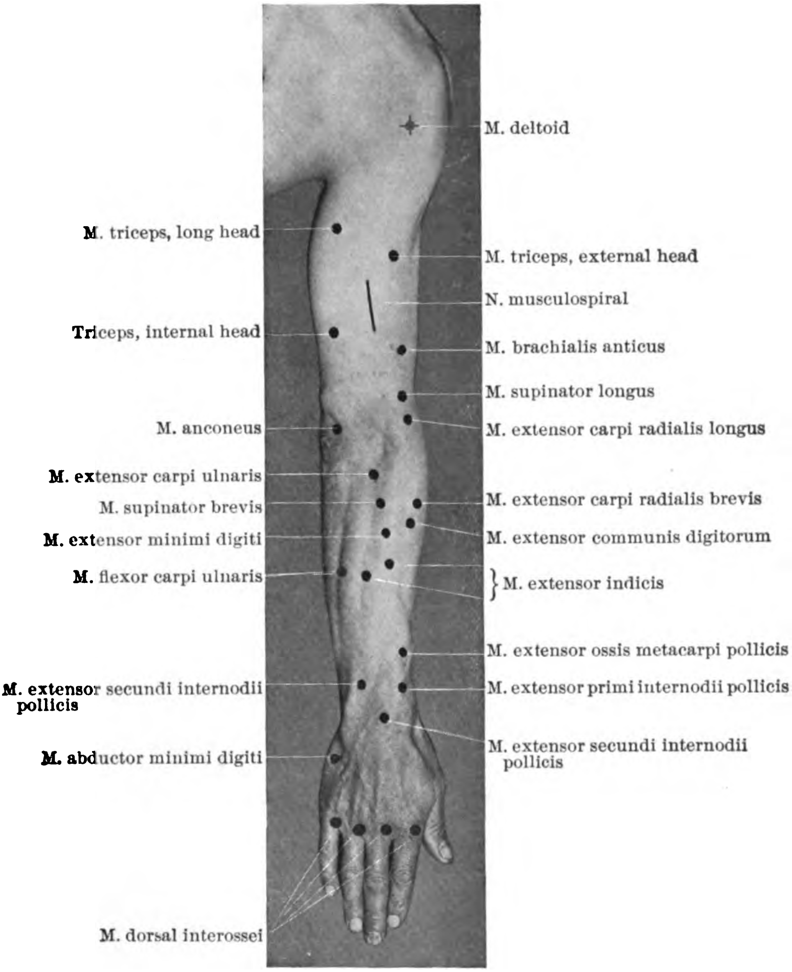
Motor points of the face and neck.

PLATE 2

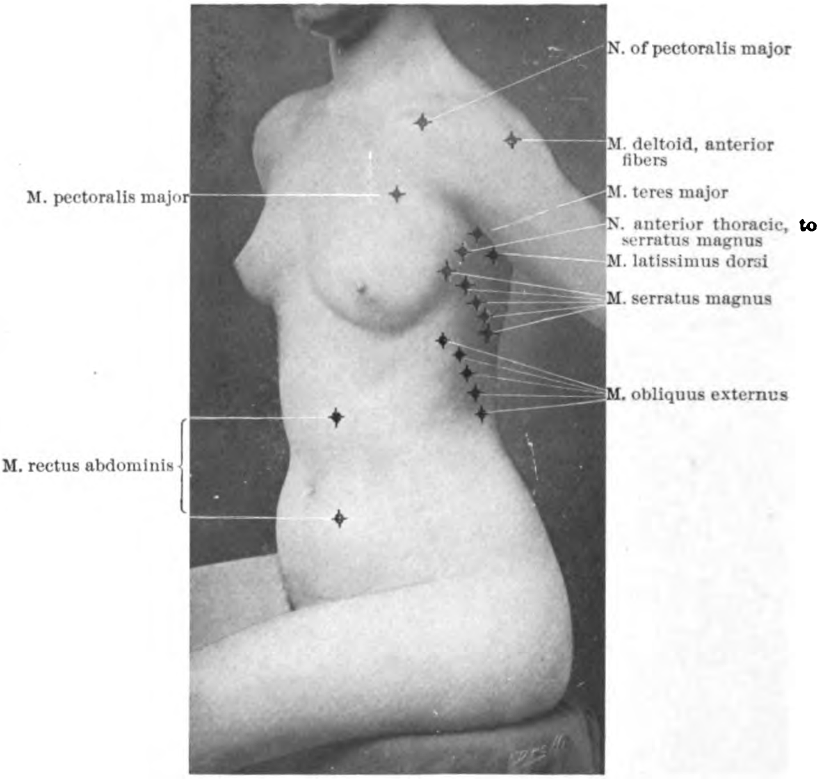


Motor points, palmar surface, of the upper extremity.

PLATE 3

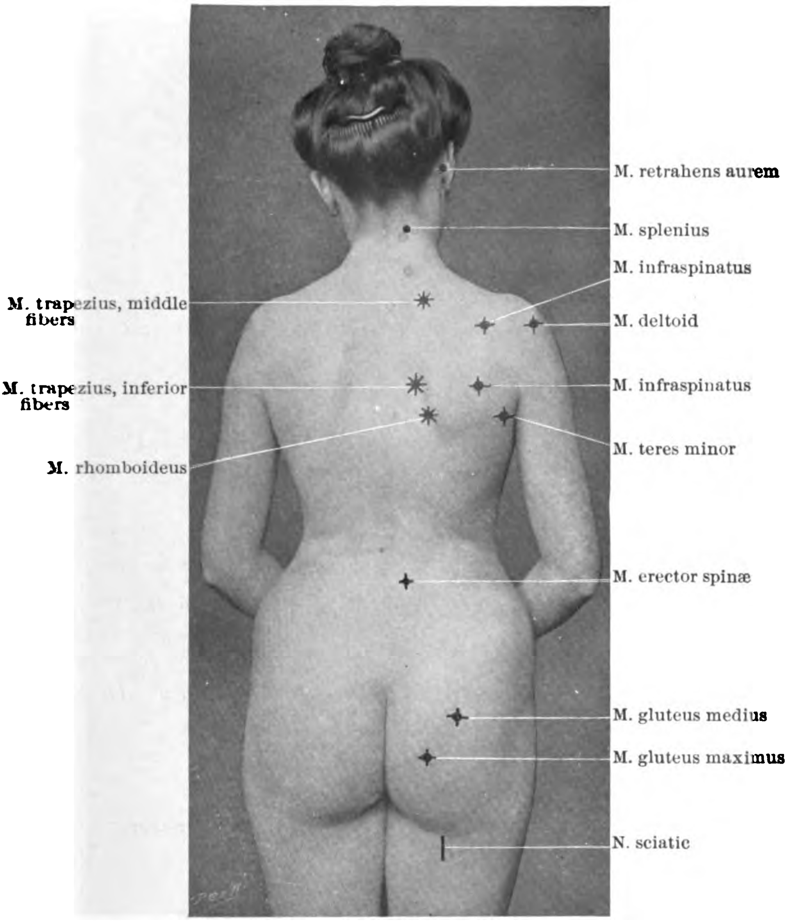


Motor points, dorsal surface, of the upper extremity



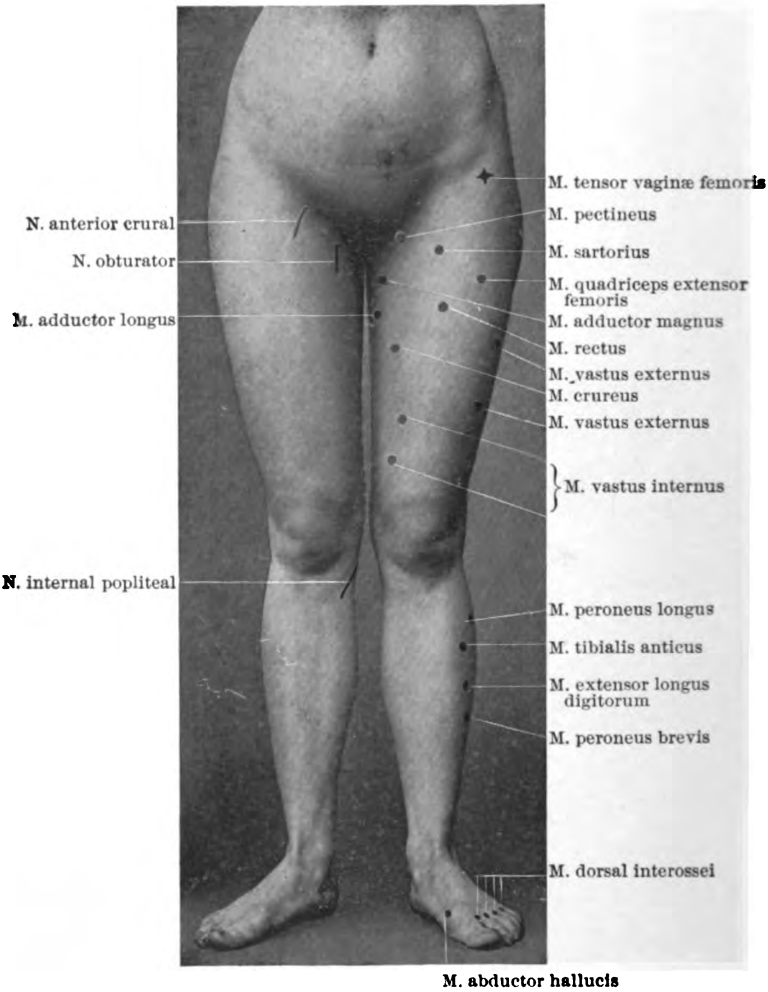
Motor points of the chest and abdomen.

PLATE 5

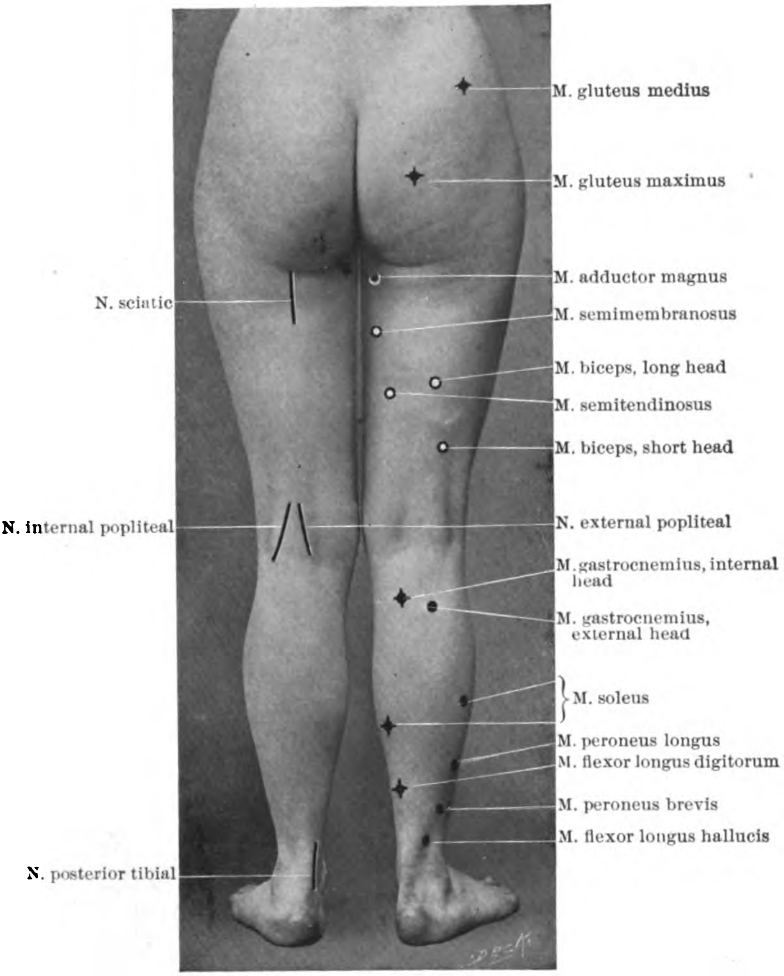


Motor points of the back.

PLATE 6

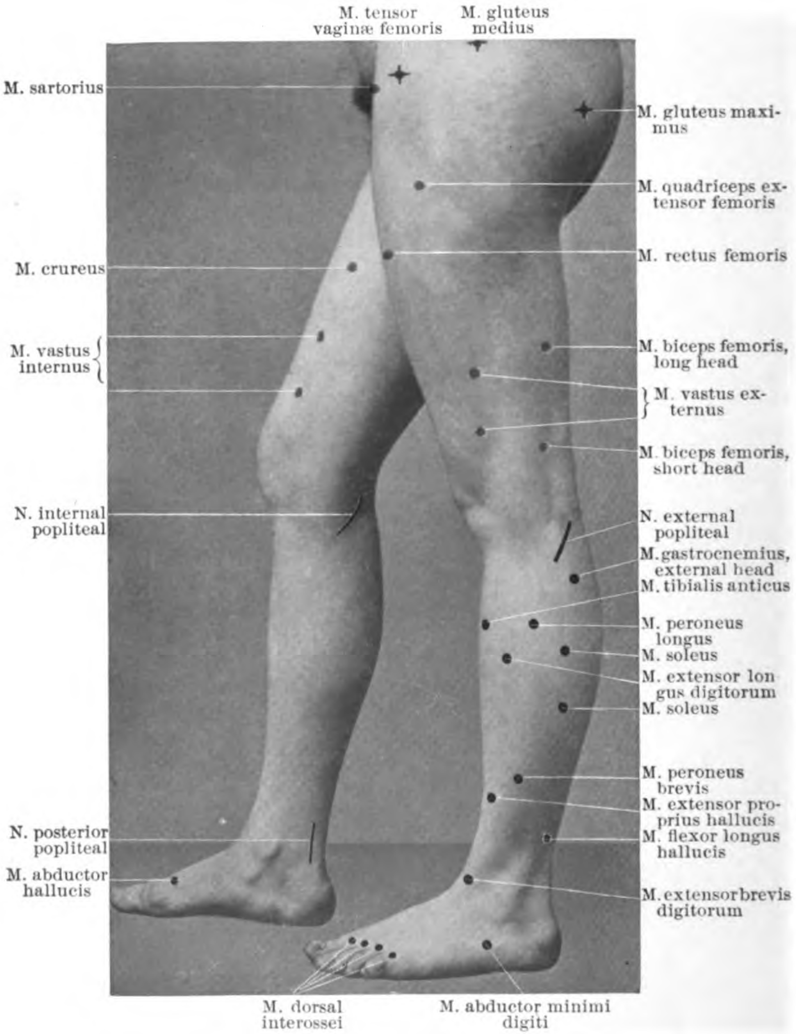


Motor points, anterior surface, of the lower extremity.



Motor points, posterior surface, of the lower extremity.

PLATE 8



Motor points, internal and external surfaces, of the lower extremity.

in women than in men, being about 1400 or 1500 ohms from one hand to the other in women, and 1200 or 1300 in men. This is with hands cleansed by washing with soap and water, and plunged in glasses containing salt solution at the temperature of the body. Holding two dry metal electrodes in the hands, a resistance as high as 100,000 ohms may be found in consequence of dryness or greasiness of the skin, and it would vary with the firmness with which the electrodes were held.

Increasing the strength of the current reduces the resistance of the body. In experiments by Weiss the current was at first 5 ma. and the resistance 1570 ohms; increasing the current to 10 ma. lowered the resistance to 1350 ohms; a still further increase to 23 ma. lowered the resistance to 1160 ohms; then a reduction to 10 ma. raised the resistance to 1260 ohms; and a final reduction to 6 ma. raised the resistance to 1340 ohms.

These figures are partly attributable to the effect of the passage of a direct current in reducing the resistance of the body, for the resistances toward the end of the experiment were less than at first with the same strength of current.

Leduc[1] does not find that moistening the skin or dilating or contracting its blood-vessels by means of heat or cold has much effect upon the resistance, but the profound anemia produced by adrenalin decidedly reduces the resistance of the skin.

The nature of ions and their degree of saturation as produced by the amperage and the voltage of the current do, as a rule, produce variations in the resistance.

Relation Between the Area of the Electrodes and the Electric Resistance of the Body.—The area of the surface of contact has quite a decided effect upon the electric resistance. With the electrode moistened with a solution of sodium chlorid and the skin already saturated with these ions, a uniform electromotive force of 6 volts produces the following number of milliamperes of current with different areas of contact. With a surface of 2 square centimeters the quantity was $2\frac{5}{100}$ ma.

Surface.	Milliamperes.
40 centimeters	4.95
36 "	4.80
32 "	4.60
28 "	4.43
24 "	4.25
20 "	4.07
16 "	3.90
12 "	3.72
8 "	3.55
7 "	3.30
6 "	3.06
5 "	2.82
4 "	2.56
3 "	2.28
2 "	2.05

These figures correspond to a resistance varying from 1200 ohms to 2400 ohms, depending upon the size of the surface of contact.

Laws of Stimulation of Nerves.—*DuBois-Reymond's law* is that the stimulation is proportional to the variations which occur in the strength of the current in a certain time, $Q = bt$.

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[1] Arch. d'Electricite med., June 25, 1905.

Hoorweg and Weiss have devised formulas ($E = a\,i\,e^{-\beta t}$, *Hoorweg;* $Q = a + bt$, *Weiss*) which are based upon the theory that the strength of the current is the important factor, but that there is a certain variation in the stimulation produced by the make and break of a galvanic current according to the rapidity with which the actual make and break are accomplished.

With a current of very short duration, such as an isolated induction discharge or the discharge of a condenser of small capacity, the time element may be disregarded in Weiss's formula. Q is the quantity of electricity necessary to produce stimulation. The value of b is practically the milliamperage of the weakest galvanic current which will produce muscular contractions when instantaneously made or closed. Then, by means of a condenser of known capacity, C, charged to different voltages and discharged, we determine the voltage, V, necessary to produce contraction. The voltage required with the galvanic current divided by the amperage gives the resistance R in the circuit.

Hoorweg's formula for stimulation by condenser discharges:

$$V = \alpha + \frac{\beta}{C}.$$

In this expression V is the voltage to which the condenser of a capacity C must be charged, and α and β are coefficients.

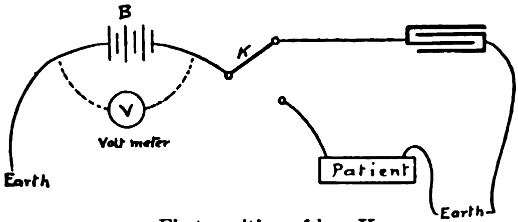
Cluzet finds that 0.2 microcoulomb discharged in a very short time (no matter by what means) produces contraction in a normal muscle. If a much greater quantity is required, it indicates hypo-excitability.

To observe single contractions from isolated induction shocks turn back the screw of the faradic interrupter until it will no longer vibrate, and make a single contact by touching it with the finger-tip.

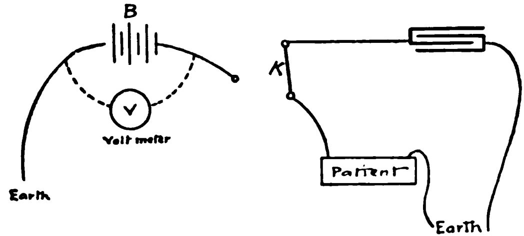
Muscles become wasted when paralyzed by organic disease of the lower motor segment (anterior cornua of the cord, motor nuclei at the base of the brain, neuritis or nerve injury). Faradic excitability becomes reduced or is lost because this form of electricity can produce muscular contraction practically only through stimulation of nerve-fibers.

Application of Condenser Discharges for Electrodiagnosis.—A condenser discharge is of such short duration that the resistance of the body does not have time materially to change. It is unidirectional, painless, and practically free from electrolysis. These facts make it a more exact means of diagnosis than the galvanic current under certain conditions.

Condensers of capacities of from 0.01 to 2 microfarads, or a divisible condenser, are required, and also a galvanic battery of 30 to 50 cells, or the direct 100 to 240 electric-light current may be used. In the simplest arrangement the condenser has one armature grounded and the other connected with a switch or Morse key, K (Fig. 274), by means of which it is connected either with one pole of the battery or with an electrode applied to the patient. The other pole of the battery is grounded. The other electrode applied to the patient is also grounded. A cell selector enables one to connect any desired number of cells in series. Or, if some other source of electricity is used, a volt controller is required. And a voltmeter connecting the two poles of the battery measures the potential to which the condenser is charged when the key connects the condenser with the battery. Turning the key in the opposite direction discharges the condenser through the patient. This condenser is charged to gradually increasing potentials until a muscular contraction is produced. Then the same test is applied with a condenser of a different capacity. There should be a certain relation between the first and second capacities, C_1 and C_2



First position of key K.



Second position of key K.

Fig. 274.—Condenser discharges for electrodiagnosis.

(microfarads), and the first and second voltages, V_1 and V_2, in health. Hoorweg designates this normal relation by the equation

$$\alpha = \frac{\frac{1}{C_1} - \frac{1}{C_2}}{V_1 - V_2}$$

The value of α (called the condenser excitability) in normal conditions is from 2 to 5, depending upon the motor point to which the condenser discharge is applied. It is reduced to 0.25 or even 0.07 in traumatic paralysis, and to 0.0006 in complete degeneration of the nerve.

The intensity of the galvanic current required to produce a minimal cathodal closure contraction is measured in milliamperes. There is a certain normal relation between this intensity i and the condenser excitability, which is expressed by the formula

$$\beta = i\ \alpha.$$

β is called the coefficient of extinction, and should be between 1 and 6.

A better way, shown in Fig. 275, diagrams A, B, and C, is to have a double pole switch by means of which the condenser may be first charged by connecting the two poles of the battery with the two armatures of the condenser. Turning the switch the other way disconnects the battery from the condenser and connects the two armatures of the latter with the patient. No ground connections are required with this arrangement. The double-pole switch may be a hand one for single discharges, or it may be of the pendulum type, giving discharges at intervals whose frequency is adjustable. In the latter case a separate battery of about three cells is usually required to operate the switch. Damp sponge or chamois-covered electrodes are used, the active one being 3 cm. (about 1 inch) square, and the indifferent one measuring 5 × 10 cm. (about 2 × 4 inches).

The voltage normally required to produce a contraction from condenser stimulation of the median nerve varies in adults and large children, and under different conditions, between 14 and 20 volts. In young children 30 volts are required, and in tetanus only 7 or 8 volts.

Repeated condenser discharges markedly increase excitability, so that a smaller voltage will produce contraction. Faradization, on the other hand, exhausts the excitability, and stronger currents are required after it has been used for a time.

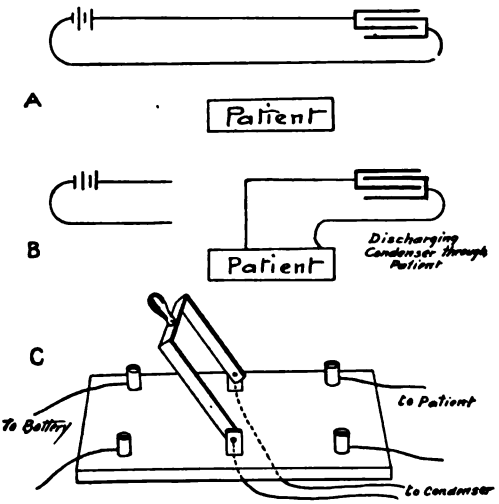


Fig. 275.—Double pole switch for condenser discharge.

With a charging potential of 100 volts and the resistance of 1000 ohms, shown by the body with ordinary wet exploring electrodes and condensers of different capacities, the following table from Lewis Jones shows the duration of discharge and twelve different degrees of muscular excitability:

No.	Capacity, microfarad.	Discharge duration, second.	No.	Capacity, microfarad.	Discharge duration, second.
1	0.016	1/24000	7	0.25	1/1600
2	0.025	1/16000	8	0.33	1/1200
3	0.05	1/8000	9	0.5	1/800
4	0.062	1/6000	10	0.66	1/600
5	0.08	1/4800	11	1.	1/400
6	0.125	1/3200	12	2.	1/200

Normal muscles require 0.01 to 0.08; muscles with partial reaction of degeneration, 0.1 to 0.6; and muscles with complete reaction of degeneration, 1 to 3 or more microfarads at 100 volts to produce contraction.

With still larger condensers longer waves should be produced, but even 2 microfarads at 100 volts produce a disagreeable shock. The best plan for securing a reaction in the most degenerate muscles is to use a charging voltage of 200 or 240 volts, a capacity of 2 microfarads, and a resistance of 4000 ohms in series with the patient. It is calculated that the duration of the discharge is increased to $\frac{1}{10}$ second in this way (Lewis Jones). (See also page 307.)

Abnormal Electric Reactions.—1. *Faradic Hypo-excitability with Normal Galvanic Formula.*—This may be found in old hemiplegia, hysteric paralysis, primary myopathies, reflex amyotrophy from joint disease, slight paralyses of rheumatic origin, or from compression or infection when the spinal centers are not involved, in slight neuritis, in locomotor ataxia, and in sclerosis en plaques.

2. *Faradic Hypo-excitability with Galvanic Hypo-excitability with Normal Formula.*—This occurs in more advanced cases of the same varieties as enumerated in the preceding paragraph.

3. *Faradic and Galvanic Hyperexcitability.*—This occurs in recent hemiplegia, Little's disease, infantile hemiplegia, sometimes in chorea, at an early stage of locomotor ataxia, in tetanus (more marked with the nerve than with the muscle), and in cholemia (more marked with the muscle than with the nerve). Galvanic hyperexcitability.

4. *Reaction of Degeneration.*—Electric examination in the case of a lesion producing degeneration of a motor nerve shows different results at three different stages: (*a*) Immediately after an injury to a motor nerve there is faradic and galvanic hyperexcitability of the nerve, with faradic and galvanic hypo-excitability of the muscles supplied by it. In the course of ten days faradic and galvanic inexcitability have gradually developed in the nerve, with faradic hypo-excitability or inexcitability and galvanic hyperexcitability in the muscles. (*b*) After the degeneration has become established, there is complete faradic and galvanic inexcitability of the nerve; faradic inexcitability of the muscle; and galvanic hyperexcitability of the muscle, with inversion of the formula so as to produce the "*reaction of degeneration,*" "RD":

$$\text{An Cl C} > \text{Ca Cl C} > \text{An OC} > \text{Ca OC}.$$

This stage gradually changes to one of galvanic hypo-excitability with sluggish contractions, but with all the other features the same. (*c*) If recovery is to ensue, a gradual return to normal reactions takes place, otherwise there is gradually a complete loss of excitability at the motor point, but excitability at the extremity of the muscle (Remak and Doumer's reaction) remains, until finally the muscle dies and all electric excitability disappears.

5. *Hypo-excitability and Sluggish Contractions.*—Degeneration is not always complete, and does not always produce even inversion of the formula. Sometimes hypo-excitability and sluggish contractions are the only symptoms upon which the electrodiagnosis of motor nerve degeneration is based.

Interpretation of the Reaction of Degeneration as Described Under Headings 4 and *5.*—This never occurs in paralysis from a cerebral lesion or from a lesion of the spinal cord which does not involve the anterior cornua. It is strictly a symptom of injury to the motor nerve and the ganglion-cells in the anterior cornua from which it springs. It is found in infantile paralysis (anterior poliomyelitis), acute poliomyelitis in adults, diffuse myelitis involving the anterior cornua, hematomyelia, traumatic and toxic neuritis, rheumatic and infective paralysis, and in the Aran Duchenne type of myelopathy, Charcot's disease, syringomyelia, and amyotrophic lateral sclerosis, and in accidental division or surgical resection of a motor nerve, or paralysis from involvement in bony callus. The reaction of degeneration does not appear in some slow cases of spinal muscular atrophy. There is only a gradual loss of galvanic excitability.

Examination for the Reaction of Degeneration.—Have the patient hold the positive electrode at some indifferent point and place the negative electrode at the motor point of the muscle. This active electrode should have a small surface, not more than ½ inch in diameter, and should be applied with a uniform pressure of about 1½ pounds. This pressure should not vary while the current is being made and broken. The author's diagnostic electrode is designed to overcome the faults which are present in electrodes where the current is turned on and off by the pressure of the same hand that holds the electrode, and by uncertainty as to the amount of pressure exerted even when this is not the case.

Starting from zero, the galvanic current is gradually increased in strength, while the current is repeatedly made and broken until a closure contraction takes place. The pole-changer is then reversed, connecting the exploring electrode with the positive and the indifferent electrode with the negative pole. The position of neither electrode is changed, nor is the pressure upon the electrode or the rheostat controlling the strength of the current changed. If a closure contraction no longer occurs, or if it is much weaker than was the negative closure contraction, there is no reaction of degeneration, but if the positive closure contraction equals or exceeds the contraction obtained when the exploring electrode was connected with the negative pole, then reaction of degeneration is present.

Only the contraction of the particular muscle under examination is to be considered, not any general motion of the limb.

Slow, sluggish contractions are the most important features of degeneration and are sometimes the only change to be discovered.

6. *The Reaction of Compression.*—This is sometimes found after a limb has been constricted by an Esmarch band. There is normal or increased faradic excitability, with galvanic hyperexcitability, and a change in the formula making CaOC much stronger than usual. CaClC>AnClC>CaOC>AnOC.

7. *The Reaction of Fatigue.*—This means that repeated contractions require stronger and stronger currents to produce them. It is only rarely observed in such diseases as paralysis of cerebral origin, hemiplegia from apoplexy, sciatica, progressive muscular atrophy, anterior poliomyelitis, and also in myasthenia.

8. *The Myotonic Reaction.*—This occurs only in Thomsen's disease. It consists in faradic and galvanic hyperexcitability for both the nerve and the muscle, and in a marked change in the form of the contraction. The galvanic cathodal and anodal closure contractions are nearly equal.

and are tonic and prolonged. Anodal or cathodal closure tetanus may occur with currents of 5 to 10 milliamperes, and sometimes anodal opening tetanus. Completely tetanizing faradic currents cause tetanus which lasts a variable length of time after the cessation of the currents, and also undulatory contractions in neighboring muscles. The latter sometimes occur with the galvanic current also. The special phenomenon of myotonia or fusion of successive muscular contractions is elicited when the galvanic currents are made and broken at moderately short intervals and are of a strength which would produce only isolated muscular contractions in a condition of health. Repeated muscular contractions, either voluntary or electrically excited, gradually exhaust the property of myotonia.

9. *The Antagonistic Reaction.*—This occurs in multiple neuritis, showing an increase in contraction under intermittent cathodal stimulation and a diminished contraction when the anode is the active electrode.

Rich's Reaction.—When this is present, the cathodal closure contraction and the cathodal opening contraction tend to become equal to the anodal opening contraction, whereas, normally, the latter requires about ten times as strong a current as the former. This reaction seems to indicate insufficient blood-supply to the nerve, but it is not always possible to tell the exact cause of this condition.

Remak and Doumer's Reaction.—This is a condition in which the muscle contracts more readily to a current applied near its extremity or near its tendon than to one applied to its motor point.

This reaction appears very promptly—within one, two, or three days after the injury to the nerve—and may be found in some cases which do not show Erb's reaction of degeneration. In the latter cases the wrong diagnosis would be made if the examination at an early stage of the case were made by stimulation of the motor point alone, for the muscular response there may be as good as normally.

In the case of a long-standing complete injury to a motor nerve all muscular contractility to stimulation at the motor point may be lost, and so Erb's reaction of degeneration could not be obtained. No response taking place, it would be impossible to say whether or not there was inversion of the normal formula. In some cases, however, even a year or more after a completely paralyzing lesion of the nerve, Remak and Doumer's reaction may be obtained (contraction from the application to the extremity of a muscle of a current which will not produce a contraction when applied to the motor point). Remak and Doumer's reaction is more marked at the anodal closure contraction than at the cathodal closure contraction.

Electrodiagnosis in Eye Diseases.—It has been known for a long time that the passage of electric currents through the eye would occasion luminous sensations, and that the making and breaking of the current and changes in its intensity were especially productive of these sensations. Several observers—Ritter, Purkinje, Burnham, Müller, Benedict, Althaus, and La Grow, among others—have studied this effect. The color and shape of the luminous subjective image have varied so greatly under similar conditions that it is probable that they are different in different individuals. It is supposed that there is no direct connection between the strength of the current and the color and intensity of this luminous image. The luminosity is quite certainly not excited by

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electrification of the brain itself. Currents which pass between electrodes placed at the two sides of the head do not produce any sensation of light, although it has been proved that such currents, even if as weak as 1 milliampere, do actually traverse the brain substance. Currents applied to the temples, however, do sometimes produce luminous sensations, and it seems probable that these currents traverse the eye or the optic nerve in part. A long series of observations by different men has shown that the sensation of color and light is due chiefly to excitement of the retina, but partly also to the excitement of the optic nerve. It will take place, for instance, after the eyeball has been removed. The strength of the current required to produce this visual sensation is very slight in the healthy eye. Placing the negative electrode upon the temple and the positive electrode upon the upper eyelid, a current of only $\frac{3}{10}$ milliampere, or sometimes only $\frac{1}{10}$ milliampere, is sufficient to excite a visual sensation in the eye. After removal of the eyeball, however, a stronger current is required to produce the effect. In one case tested eight days after enucleation a current of 1 milliampere was required; in another case one year after enucleation $1\frac{6}{10}$ milliamperes were required, and in one case, five years after enucleation, 3 milliamperes, and another, ten years after enucleation, 5 milliamperes. In the latter case, however, the perception of light was noticed in the sound eye; evidently the current had penetrated through to the healthy eye. Different diseases of the eye cause variations in the luminous sensations produced by electricity. Opacities and similar abnormalities of the refracting media do not result in any abnormal reaction to electricity, but most changes in the optic nerve and in the retina do result in very great impairment of this reaction. It may, therefore, be used as a delicate means of diagnosis. The most exact way of applying this test is based upon the secondary reaction. This is a light independent of the colored luminous image, and is manifest at the making and breaking of the current, and is produced even when the current is too weak to cause the colored luminous image. In testing this secondary reaction the intensity of the current is increased until one has produced the primary luminous image—the primary reaction. After this the current is progressively reduced until it becomes so weak that the making of the current still produces a sensation of light, but the breaking of the current no longer produces any luminous phenomenon. This is the minimum current which Darier calls the secondary reaction, and in a great many observations it has been found that this secondary reaction in a healthy subject is very uniform—that it is almost always between $\frac{1}{10}$ and $\frac{3}{10}$ milliampere. In the case of advanced diabetic retinitis with papillary atrophy the secondary reaction requires a current of at least $\frac{8}{10}$ milliampere. The same increase in the current required is noticed in cases of old hysteric amaurosis, and eyes which have become practically blind from disuse in consequence of strabismus. As a means of diagnosis it is subject, of course, to the intelligence and imagination of the patient, but this is also true of the measurement of the visual field. It is of experimental rather than practical interest.

Electrodiagnosis in Ear Diseases.—This is largely a matter of the production of sensations of noise produced by electric stimulation (page 454), and also of the production of vertigo by galvanization.

It may often decide between a neuropathic and an organic lesion; also the seat and importance of the lesion. Ear lesions often cause the muscular sound due to faradization to be more distinctly heard than in normal ears.

Voltaic Vertigo.—This is a condition producing certain subjective and objective symptoms, caused by the application of a constant or galvanic current from electrodes 1 cm. in diameter, placed one in front of the tragus of the right ear and the other in a corresponding place on the left side. It has a certain diagnostic value in diseases of the middle and especially of the internal ear. The patient feels dizzy and it seems as if the outside world were moving toward the cathode, sees sparks before the eyes, and hears a noise in the ears. There is nystagmus or oscillation of the eyeballs if the current is strong enough. An important objective symptom is inclination of the head to the side upon which the positive pole is placed. This symptom was first noted by Babinski, who has also found that a rotation of the head toward the same side may be produced by applying the electrodes in a special way.

The condition is produced normally by a current of 2 to 4 ma., while in some diseased conditions of the labyrinth or of some other part of the internal ear, or an abnormal condition of the cerebrospinal fluid, it may require a current of 10 or 15 ma. In some cases of bilateral disease voltaic vertigo cannot be produced at all. If the head will incline toward one side and not toward the other when the polarity is changed, this fact shows that the lesion is unilateral.

The condition is of diagnostic value in determining whether deafness after an accident is due to hysteria or malingering or to an actual deep lesion of the ear. Other cases of deafness and of Ménière's disease, and of intracranial tumors and of hypertension of the cerebrospinal fluid, cause modifications of voltaic vertigo which are an important aid in diagnosis.

An organic lesion of one internal ear causes inclination toward that side, no matter what the direction of the current.

Faradic Contractions in Myasthenia.—Normally, the myograph shows that the muscle remains uniformly contracted as long as the influence of a faradic current is applied, or at any rate for a considerable length of time. Fatigue does not begin for a long time. In myasthenia there is a steady fall almost from the beginning. The flexor of the middle finger is a desirable muscle for this test, and marked abnormality is found in alcoholism, pellagra, general paralysis, dementia præcox, senile dementia, neurasthenia, and epilepsy. Tracings in these conditions have been published by Pariani.[1]

Electrodiagnosis in Alcoholic Peripheral Neuritis.—There may be motor troubles, with or without the reaction of degeneration. In the first class of cases faradic excitability is a little diminished, and so is galvanic excitability; but there are no qualitative changes, though there is hypersensitiveness of the skin to both currents. Cases with reaction of degeneration are quite rare.

Alcoholic cases without motor troubles present practically normal electric reactions.

Detection of Malingering or Hysteria in Paralysis after Injury.—The fact that voluntary motion returns sooner than normal electric reactions after a nerve injury is extremely important. In a case in which paralysis and the reaction of degeneration have followed an injury or a disease, the return of faradic excitability without the return of voluntary movement is considered proof of malingering or hysteria.

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[1] Rivista di Patologia neurosa e mentale, November, 1905.

Record of Electrodiagnostic Examination.—This should state the faradic and galvanic excitability and qualitative changes in the same muscle or nerve on both sides of the body; thus:

Vastus Externus Muscle.

Right.			*Left.*		
Faradic excitability	D	= $3\frac{1}{2}$ cm.	Faradic excitability	D	= $7\frac{6}{10}$ cm.
Galvanic excitability	Cacc	= 13 ma.	Galvanic excitability	Cacc	= 5 ma.
	Ancc	= 13 ma.		Ancc	= 8 ma.
Qualitative change, slowness.			Qualitative change, none.		

If the faradic coil has an adjustable number of turns in the secondary coil and rate of vibration in the interrupter, these should be stated. They should normally be the same for both sides.

Various graphic charts have been devised, but the simple written record is excellent, especially if supplemented by a note to the effect, for instance, that the "galvanic and faradic excitability are both reduced, and there is a slowness of contraction, but no inversion of the normal formula."

If the Leduc apparatus is used, the number of interruptions per minute and the fraction of each period during which the current flows should be stated, and also the smallest number of milliamperes which causes contraction.

If a condenser is used, its capacity should be recorded, and also the voltage to which it must be charged, so that isolated discharges will produce contraction; also the voltage which will produce tetanus from rapidly repeated discharges.

The Electric Resistance of the Urine and of the Blood.—The normal resistance of the urine at 65° F. in a U-shaped electrolytic tube is about 45 ohms. The greater the percentage of chlorids, phosphates, sulphates, and other salts, the less is the resistance. The electric resistance is unnaturally great in pneumonia, diabetes, acute or chronic Bright's disease, and pernicious anemia. This means insufficient function on the part of the glomeruli of the kidneys.

The normal resistance of the blood is $93\frac{1}{2}$ ohms when measured by Dawson Turner's method.[1] Five cubic millimeters of freshly drawn blood are placed between two cup-shaped electrodes 3 mm. in diameter, which are covered with spongy platinum and fixed at a distance of 75 mm. The electric resistance of the blood may vary in health from 85 to 130 ohms. The red-blood cells are non-conductors, and the more abundant they are, the greater is the resistance. The saline constituents, especially sodium chlorid, are good conductors, and the more abundant they are the less is the electric resistance.

The electric resistance of the blood-cells and of other cells is measured by a method proposed by Nernst. The resistance of a liquid is first measured and then blood-cells are added to the liquid in a certain proportion and the resistance again measured.

Rudolf Höber finds that the blood-cells have a conductibility equal to that of a decinormal solution of potassium chlorid, while the entire blood has a very much greater resistance.[2]

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[1] British Medical Journal, July 28, 1906.

[2] Archiv. für die gesam. Physiol., cxxxiii, 237, 1910.

The electric resistance of the lymph is regularly less than that of the serum.[1]

The **electric conductivity of the human saliva** undergoes daily oscillations which show that it contains ionizable salts in greatest amount on rising, then reduced, not much influenced by light repasts, but decidedly increased by the principal meal.[2]

The **electric conductivity of cows' milk** is about 48.7, 10^{-4}, and it has been suggested by Rinaldo Binaghi[3] as a test for adulteration.

The Hemorenal Index.—This is the quotient obtained by dividing the electric resistance of the blood by that of the urine, and it varies normally between 2 and 3, the average being $\frac{93.5}{45} = 2.08$.

An increase in the hemorenal index means a diminution in the salts in the blood, or an increase of those in the urine, or both. This is sometimes found in chronic rheumatism.

A diminished hemorenal index, such as $\frac{\text{Resistance of blood},}{\text{Resistance of urine},} \frac{51}{115} =$ 0.44, was found in a case of pernicious anemia. It indicates inability of the glomeruli to transmit salts from the blood to the urine to a sufficient extent. It explains the danger that accompanies *x*-ray exposures in pernicious anemia, which throw increased excretory work upon kidneys already deficient.

PROGNOSIS BASED ON ELECTRODIAGNOSIS

When electrodiagnosis and other means show that the paralysis is due to a cerebral or a spinal-cord lesion, the prognosis depends upon the nature of the lesion more than upon the electric reactions. It is in the case of peripheral nerve lesions that the most valuable prognostic knowledge may be obtained from electrodiagnosis. A case of facial paralysis from exposure or rheumatism may show a continuance of normal electric reactions, and if so, recovery may be expected in about three weeks, or there may be galvanic and faradic hypo-excitability, meaning that recovery will take two or three months. The presence of the reaction of degeneration in such a case indicates a probable duration of six months, with a possibility of permanent paralysis. Lesions of other peripheral nerves are judged in a similar way.

Complete loss of nerve excitability, with greatly increased galvanic muscular excitability, with sluggish contractions, indicates a severe degenerative process. The possibility of some regeneration remains, however, as long as any electric excitability is present, but if a year passes without return of faradic excitability, and if the muscular atrophy has been rapid and great, only slight improvement can ever be hoped for.

With an acute lesion and loss of faradic excitability inside of a week or ten days considerable atrophy will follow, and the motor power will be slow to return.

If two or three weeks pass before faradic excitability disappears, the paralysis will last many months, but there will be less atrophy.

If faradic excitability remains normal or is but slightly reduced, recovery will begin in a few weeks or months, and will probably be complete.

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[1] Luckhardt, Amer. Jour. of Physiol., xxv, 345, 1910.

[2] G. Polara, Archiv. italiennes de Biologie, liv, 22, 1910.

[3] Biochemisches Pathologie und Zur allgemeinen Pathol., xxix, 60–79, 1910.

IONIC MEDICATION BY ELECTROLYSIS

An electric current may be made to carry medicinal substances into the tissues to a sufficient extent to produce certain physiologic and therapeutic effects. The positive electrode is usually selected for the active one, because it is generally convenient to use a solution of some salt of a basic medicinal substance. When a salt is decomposed by the current, the ions representing the base travel into the body on their way to the cathode, and the application is known as *cataphoresis*. The effects of basic ionizations are manifested chiefly in the tissues close to the positive pole, though these ions may produce chemic reactions in the liquid with which the negative electrode is moistened. It is easily demonstrated that particles of a substance may pass entirely through the body, so as to be found on the surface of the opposite electrode from the one originally moistened with it. It is not at all certain, however, that particles of the substance exert any influence upon the deeper tissues through which they are transmitted. The effect seems to be due to the liberation of an element or a radicle in a nascent state from the solution in which the electrode is moistened; and it is an immediate effect upon the first tissues subjected to it. The ions are transmitted through the deeper tissues in a condition in which they generally do not form combinations with the substances making up these tissues, or with ions traveling in the opposite direction. The two substances in the latter case may have the strongest possible affinity for each other, and still show no chemic combination except at the two poles. The same force called electrolysis, which is strong enough to dissociate elements which can be separated in hardly any other way, is operative in largely preventing anything but a local effect as the direct result of electric ionic medication.

Merely dissolving a substance in water converts a considerable part of it into ions. *Ionic medication* is, therefore, not a specific enough term in itself to indicate the subject of this paragraph.

Leduc[1] has summarized our previous knowledge of the subject of the electric introduction of medicines, and has added many valuable observations of his own.

It has long been known that electrolysis takes place at any point of contact between the skin and an electrode which is a much better conductor; that the primary effect at the anode is to liberate chlorin, from the sodium chlorid of which the conducting portion of the body is practically a solution, and oxygen, from the water in which it is dissolved. The chlorin is liberated at the positive electrode, which it attacks, and an oxychlorid of the metal or other base is formed. A continuation of the effect dissociates the oxychlorid of the metal and carries metallic or other basic ions into the tissues, while the chlorin and oxygen attack fresh portions of the metal. A similar process goes on at the cathode where sodium and hydrogen are liberated, and immediately combine

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[1] Ions et Medication ionique, Paris, 1907.

with the acid element of the electrode if the latter is a salt. A continuance of the process dissociates this intermediate hydrogen or sodium compound, and carries the liberated acid ions into the body.

If one wished to produce the effect of hydrocyanic acid, the negative electrode would be wet with a solution of potassium cyanid, while to produce the effect of strychnin the positive electrode would be wet with a solution of strychnin sulphate.

Experiments in Cataphoresis.—S. Salaghi[1] has performed the following experiment with a view to arresting and fixing in the tissues the ions which are carried there by a galvanic current: Four glasses, A, B, C, and D (Fig. 276) are placed in series. The positive electrode of a galvanic battery dips into A, which contains a solution of nitrate of silver. This glass is in electric connection by means of a strand of cotton mesh with B, which contains a solution of sodium nitrate. C also contains sodium nitrate solution and is connected by a cotton mesh with D, which contains a solution of sodium hyposulphite. B and C are connected by a tube containing a dog's sciatic nerve immersed in oil. A current of 12 ma. passing steadily for twenty-four hours will produce a precipitate of silver in several centimeters of the length of the nerve at the end nearest the anode. The precipitate is found exclusively in the myelin of the nerve-tubules.

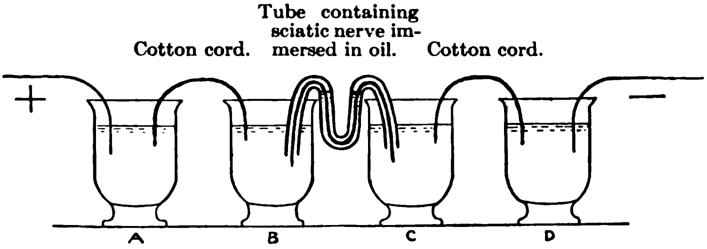

Fig. 276.—Fixation of ions in the tissues after cataphoresis.

Another experiment by Leduc consists in having two rabbits separated by absorbent cotton wet with potassium cyanid; the rabbit connected with the anode is poisoned. But if the cotton were wet with strychnin hydrochlorate, the rabbit connected with the cathode would be poisoned.

In an oral communication to the author Dr. G. Betton Massey states that a piece of raw meat to which a galvanic current is applied through electrodes of amalgamated zinc (zinc dipped in acid and then in metallic mercury) will show a gray discoloration, indicating a transportation and deposit of metallic mercury.

Rate of Transportation of Ions.—It is important to remember that the rate of passage of the electric current, about the same as that of light, is a very different thing from the speed at which ions move through the same electrolyte. Different ions move at fixed rates of speed, which for each ion increase with the electromotive force which drives it, and is diminished with the length of electrolyte through which the current has to pass. Kohlrausch gives the following as the rate of speed when

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[1] Arch. Ital. de Biologie, vol. xliii, 35, 1905.

an electromotive force of 1 volt acts through 1 centimeter of length of electrolyte:

Silver ions move at the rate of 0.166 cm. per hour.
Lithium " " " " " 0.094 " "
Sodium " " " " " 0.926 " "

Cerebral Effects of Medicinal Electrolysis.—Gautrelet[1] has tested the effect of the strong currents used in electrolysis near the head. Using the positive electrode with a surface of 100 square centimeters applied to a rabbit's ear, while the indifferent electrode is applied to the thigh, a current of 30 ma. is allowed to flow. The effects produced are of two kinds: an early effect, due to the electric current itself, and always seen, regardless of the nature of the electrolyte used to moisten the electrode, and a later effect, which is sometimes seen when such a substance as strychnin is used for the electrolyte. The effects directly due to the current are at first symptoms of peripheral irritation of the trigeminal nerves, movements of the face and of the eyes, and an increase of the sensibility of that region. There is a stimulation of the cerebellum, causing movement of the opposite paw; and bulbar stimulation, causing a change of the cardiac and respiratory rhythms and increased frequency of respiration; and a stimulation of the medulla, producing contractions of a good many different muscles. These phenomena of stimulation amount to epileptic convulsions in the course of fifteen or twenty minutes, the convulsions being at first tonic and subsequently clonic. The eyes protrude, the pupils are dilated, the heart beats fast. At a subsequent stage paralytic symptoms develop, the corneal reflex on the opposite side from the anode gradually becomes abolished; spontaneous movements cease, and movements of the nostril and face on the same side are abolished; the face is drawn toward the opposite side. No reflex occurs from a pin-prick; sensibility disappears from the face and all parts of the body. In these experiments an application of about one and one-half hours was required to induce a general paralytic condition, which was usually but not always recovered from, a small proportion of the animals dying.

A very different result takes place when the circulation in the ear is restricted by a clamp applied to the base of the ear; in a very few minutes the heart becomes regular, respiration very rapid, and paralytic phenomena are observed, especially Cheyne-Stokes respiration. Death ensues in about an hour from asphyxia, the blood being found black and containing unreduced hemoglobin. In this experiment few if any symptoms of stimulation, and scarcely any convulsive movements, occur.

If a substance, such as strychnin, is used, its special effects become apparent after a much longer time than the effects directly due to the current. If the circulation in the ear is not impeded, the characteristic strychnin convulsions take place after fifty minutes' application, and the animal dies almost immediately. When the circulation is cut off, the strychnin symptoms do not occur even after the cessation of the current or of the direct results of the current; but if the clamp is removed before the animal dies, the characteristic symptoms of strychnin-poisoning develop a few hours or a day later. Of course, in the latter case the current was stopped entirely after the application of three-quarters of an hour.

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[1] Arch. d'Elec. med., July 10, 1907.

Distinction Between Electric Ionic Medication and Other Ionic Medication.—Dissolving any substance produces a certain number of ions of that substance, and it is probable that all medication depends chiefly upon these active particles of the different substances.

Electric ionic medication is the production of ions, and their introduction into the body by means of an electric current.

The Author's Technic for Electric Ionic Medication.—A four-cell bath is used (p. 424). Three of the shallow glass trays contain a solution of sodium bicarbonate, and the fourth tray a solution of the medicine to be introduced. The electrode in each tray is a carbon plate, and is covered by a piece of indurated fiber and felt. Another piece of felt is wrapped around the part at which the medicine is to be introduced, and the whole is dipped into the tray containing the medicated solution. This tray is connected with the positive wire from a table (p. 446), which supplies galvanic, faradic, and rhythmic and other currents derived from the 110-volt direct electric-light circuit. The volt controller and the rheostat are both adjusted so as to give no current. The connections are made for the galvanic current, and the rheostat and volt controller are gradually changed until the milliamperemeter indicates that a current of 20 or more milliamperes is passing through the body. More or less burning sensation is usually to be expected at the place where the medicine is introduced, and the amount of pain furnishes a guide to the amount of current permissible. The four-cell bath referred to allows the indifferent electrode to be applied to either foot or either hand, and enables one to change from one to another by moving the wire from one binding-post on top of the table to another. A burning feeling in the foot or hand at the indifferent electrode is an indication for changing from one limb to another, but before this is done the current is gradually reduced to zero. The current is gradually increased to the original strength after the new connection has been made. For the heaviest currents three of the trays may be connected with the negative pole of the galvanic current, the more extended surface of contact with three different extremities at the same time preventing any discomfort from the indifferent electrode. This, however, does not lessen the painful effect at the active electrode, and an anesthetic is required in some cases, as in the use of a metallic zinc electrode of small size covered with felt wet with a 5 per cent. solution of zinc sulphate and a current of 40 to 80 ma. for the cure of rodent ulcer. Weaker currents may be used for the same cases without an anesthetic.

Adrenalin cataphoresis is used as a means of blanching the tissues previous to the application of the ultraviolet ray, which will not penetrate tissue filled with red blood. A small electrode is used, which terminates in a hard-rubber receptacle, for the solution (1:1000 adrenalin chlorid), and the bottom of which is formed of porous membrane. This is the active positive electrode. The other electrode may be held in the hand, and a continuous current of about 5 ma. be allowed to flow for about five minutes.

Mercuric Cataphoresis.—This term is usually applied to the method introduced by Massey. Extremely heavy currents of about 100 ma. or more are applied from the active positive electrode, consisting of sharp pieces of zinc amalgamated with mercury, thrust into the tissues while the patient lies upon a large indifferent negative electrode. A general anesthetic is required. There is coagulation necrosis or acid necrosis of the tissues for almost ½ inch around each metal point connected with the positive pole, and the portion of tissue thus destroyed dries up, and eventually, after one or more weeks, separates, leaving a granulating surface.

Correct technic is extremely important. The indifferent negative electrode had better be a pad of kaolin laid over a smaller sheet of metal, which it more than covers. Any small area of metallic contact or markedly greater conductivity would permit a more concentrated flow of the current, and produce, at the indifferent electrode, a negative burn, which is characterized by alkali necrosis or colliquative necrosis—a moist gangrenous process like that produced by the action of a caustic alkali. The patient is under the influence of an anesthetic, and so cannot give warning of the occurrence of a burn. The positive wire may be divided into about five strands, and it is best for the zinc points (pieces of sheet zinc, such as signs are painted on, about ¼ of an inch wide at the base, about 3 inches long, and tapering to a very sharp point) to be soldered to the copper wires. If this is inconvenient, they may be bent around the wire and securely pinched. The points are galvanized by dipping them first in dilute acid and then in metallic mercury. The first point should be introduced before the current is turned on, and a rheostat should be used to very gradually increase the strength of the current from zero to 30 or 40 ma. Then another point is gradually introduced, and it will be found that the milliamperemeter registers an increased current, due to the larger area of contact. Other points are introduced so as to transfix the tissues all around, and, if practicable, beneath the growth. The current may then be found to be 50 or 60 ma., the increased area of contact at the metal points having greatly reduced the resistance at the positive pole, while the resistance at the negative pole has not been changed. Additional current is now turned on very gradually until 100 or even 200 ma. are indicated by the milliamperemeter. The flesh is seen to turn white, and a white froth exudes from the different punctures. The exact length of time that the current should be allowed to flow varies with the amount of tissue that is to be destroyed. It is usually between five and ten minutes. The current must be turned off just as gradually as it has been turned on, and the last metal point must not be removed until the current has ceased to flow. The 110-volt direct current is most suitable for the work. This may be obtained from the direct 110-volt electric-light circuit, or from the alternating electric-light circuit, by a rotary transformer or a storage-battery or a galvanic battery of the necessary number of cells to produce about 110 volts may be used.

This treatment has been applied to cancers of the breast and tongue, localities where turning the current on or off suddenly would cause serious shocks.

The advantages of this treatment are the freedom from hemorrhage, the complete destruction of the part to which it is applied, the presence of a sterilized and usually dry slough, which changes into a dry scab and comes away by natural processes.

The disadvantages are that it does not have a selective action upon the morbid tissue, nor one extending beyond the area actually destroyed, and that its cicatrices are very bad compared with those left after a case has been cured by the *x*-ray or by surgical removal and a plastic operation.

While the method is certainly a valuable one for use in occasional special cases, it may not be unfair to characterize it in some other cases as an imperfect form of surgery. There is a question as to whether the destructive effect is at all due to the transportation of mercury into the tissues, or whether it is due altogether to the action of the electric current. The author feels that the latter is the chief factor in the case.

The method has been used in cancer of the neck of the uterus, as well as in external growths, like those mentioned above.

Cocainization by Cataphoresis.—The most successful method is to moisten the felt covering of the positive electrode with a 10 per cent. solution of cocain hydrochlorid in guaiacol, and to apply a current of 5 ma. for about five minutes. This produces cutaneous anesthesia, but a doubt remains in the author's mind as to whether it is any greater than would be accounted for by the action of the guaiacol (a carbolic-acid derivative) without an electric current. The method has been employed for neuralgia, for the pain in locomotor ataxia, and as a preparation for small superficial operations.

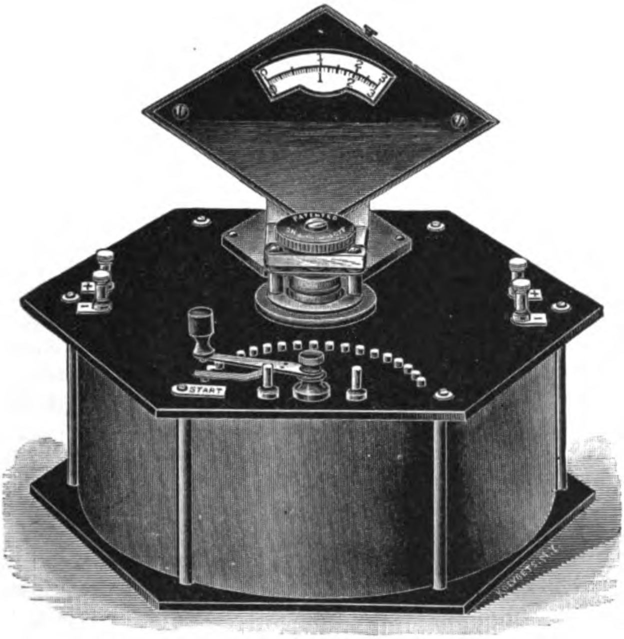

Fig. 277.—Dental fractional volt selector for cataphoresis.

Fig. 277 shows a suitable volt controller for dental cataphoresis.

Electrolytic Medication in Middle-ear Disease.—The materials employed by Malherbe[1] are solutions of sodium chlorid, potassium or sodium iodid, and pilocarpin nitrate. The strength of the solutions varies from 2 to 5 per cent. and the active electrode (positive with the first three substances and negative with pilocarpin) consists of a pledget of cotton wet with the solution, and placed in the external auditory meatus in contact with the outer surface of the drum of the ear. The other

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[1] Arch. d'Elect. med., July 10, 1907.

electrode is an olive-shaped one with an insulated stem, and is introduced through the Eustachian tube until it touches the inner surface of the drum membrane. Rather strong constant currents of 1 to 3 ma. are used for seven or eight minutes three times a week. There is a feeling of warmth or of burning. There is a beneficial effect upon sclerotic and cicatricial conditions.

Malherbe has treated tubal catarrh in the same way, having the anode in the external auditory meatus wet with a 1 per cent. solution of zinc chlorid and the cathode in the Eustachian tube.

Chlorin Ionization for Fibrous Ankylosis, Sclerosis, Dupuytren's Contraction, Sclerodactylia, etc.—The benefit which has long been known to follow the application of the constant current in these cases may be due in part to chlorin ions from the salt solution often used to moisten the electrodes. The specific object of applying these ions requires that the active electrode should be a large one, so as to permit of the use of strong currents of 20 to 50 ma. and that it should be the negative electrode.

Copper Electrolysis for Ring-worm.—This is a practicable method, but has not been employed to any extent. The object is to carry an antiseptic agent into the hair-follicles. The strength of current depends upon the area of contact: the application should not be strong enough or long enough to cause pain, but it must cause a distinct sense of warmth.

Copper Cataphoresis for Fistulas About the Jaw.—A suggestion by the author is to make use of copper electrolysis for these cases, after making sure that there is no retained broken root or root filling. A small area of necrosis can be cured by this means. The current should be 6 ma., or as near that strength as the patient can stand. The positive electrode is a pure copper rod introduced into the fistula, and the negative electrode is applied at some indifferent place.

Copper Cataphoresis for Infected Punctured Wounds with Chronic Fistulas.—A copper positive electrode is passed into the fistula, and a current of 6 or 8 milliamperes is allowed to flow for six or eight minutes, when the current is gradually reduced and a reverse current of 2 or 3 ma. is allowed to flow for a short time to loosen the electrode from the flesh. Treatments are given once a week, and result in a cure in three or four weeks.

Magnesium Ionization for Flat Warts.—A piece of absorbent cotton 2 cm. in thickness and with a surface of 100 cm. was moistened with a 5 per cent. solution of magnesium sulphate and formed the positive electrode. A current of 10 ma. was applied for fifteen minutes. Eight days after the first treatment the skin was smooth, and over almost all the surface treated the warts had become flattened and effaced. Some disappeared without leaving any trace. Most of them, however, were replaced by a little yellowish-brown spot; others felt a little bit rough. Only two treatments were required at intervals of eight days, and five or six days after the last treatment the skin was entirely normal.

This is the history of a case of multiple verruga planus of the face, treated in this way by Bordet, after all the usual methods of treatment had failed, and even after the application of high-frequency sparks had produced little effect.

Magnesium Ionization in Fungating Warts.—A case in which this treatment was tried by Bordet did not yield promptly. The electrode measured 60 sq. cm., and a current of 15 ma. was applied for fifteen minutes. Seven or eight small flat warts disappeared in the course of two or three treatments, but the fungating ones were so little affected that he destroyed them by the galvanocautery.

Iodin Anaphoresis for Goiter.—A solution of potassium iodid or a solution of iodin in one of potassium iodid is used to moisten the felt covering the negative electrode. The process is one of anaphoresis, not cataphoresis, because the active agent is one which seeks the anode instead of the cathode. The electrode must be a large one, curved around the neck, and a current of about 100 ma. for ten minutes is required. The positive electrode is a large one, and is placed at some indifferent point. Particular care must be exercised in turning this extremely powerful current on and off gradually. Applications are made every day. They are quite painful.

The effect is beneficial, but seldom causes the complete disappearance of the tumor. It is possible that it may be due practically entirely to the effect of the electric current and not to the iodin.

Iodin Anaphoresis for Chronic Suppurative Adenitis.—A method which is useful in cases where it is very desirable to avoid an incision and consequent scar is by aspiration of the pus, injection of a solution of iodin or iodid of potassium, and introducing a needle, insulated except at the point, and connected with the negative pole of the battery. The other electrode is applied at some indifferent place. A current of 10 or 15 ma. is gradually turned on and allowed to flow for ten minutes. Three or four applications usually effect a cure.

Iodin Ionization for Gonorrheal and Tabetic Arthritis of the Knee.—Successful cases have been reported by Giovine.[1] A solution of potassium iodid is used to moisten the large negative electrode which is wrapped around the joint.

Zinc Cataphoresis for Fistula in Ano.—These cases have always been extremely difficult to cure by this method, but an improved technic suggested by Bilinkin has resulted in a number of cases being cured. The positive electrode consists of the finest kind of a zinc rod or needle, and it is coated with paraffin except for 1 cm. at its distal extremity. It is introduced to the bottom of the fistula, almost but not quite entering the rectum. A current of 6 ma. flows for three minutes, and the bowels are kept constipated for three days by means of opium. At subsequent treatments the electrode does not pass so far into the fistula, and the strength of the current is gradually reduced. From six to twenty treatments are required to effect a cure. It is most likely to succeed in cases where the patient is strong and has no tuberculous trouble. It may do considerable good, however, even in tuberculous fistulas.

Zinc Ionization for Epithelioma.—The best solution is 1 per cent. chlorid of zinc. Leduc uses a current of 2 ma. per square centimeter of surface to be treated, and an application lasting fifteen or twenty minutes. Lewis Jones uses much stronger currents, but still quite endurable, and a shorter application. Cocain may be required, but not a general anesthetic. A zinc electrode is used, and cotton wet with the solution may be tied around the electrode or simply laid upon the ulcerated surface. The effect of an application of 10 ma. for ten minutes is to impregnate the superficial tissues with zinc ions and to turn them a dead-white color, which, however, does not indicate necrosis. A

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[1] Riforma Medica, November 2, 1907.

little later the surface becomes red and remains somewhat inflamed for a week. Soothing applications are required, and no further electrolysis probably until two or three weeks after the first application. Two or three applications are required.

Zinc Electrolytic Medication in Gonorrhea.—A soft-rubber catheter with multiple eyelets is used to irrigate the urethra with some solution, such as ½ per cent. solution of sulphate of zinc, which forms the positive electrode for a current of from 1 to 10 ma. Bouchet[1] makes the electric connection with the liquid by the use of a fine platinum wire, which passes through almost the entire length of the catheter, and which is fastened to a metal tube inserted between the tube from the irrigator bag and the catheter. It is to this metal tube that the positive wire is secured. The other electrode is applied to any other indifferent region. An irrigation with 2 quarts of solution is enough for each application. In acute cases, where the treatment is begun on the first or second day of the disease, Bouchet has found that daily treatments cause immediate disappearance of the discharge and sterilize the urethra of gonococci in fourteen days. In 30 chronic cases he obtained a complete cure in three or four weeks by applications made every other day.

Zinc Cataphoresis for Alopecia.—Leduc's[2] experiments upon rabbits rendered bald by tinea show that the application of a positive electrode wet with a 1 per cent. solution of chlorid of zinc causes rapid growth of the hair.

Chronic Hemorrhagic Endometritis and Chronic Ulcer of the Leg.—Zinc cataphoresis is excellent in both these conditions.

Lithium Ionization in Gout.—Guilloz's method has been used successfully in a large number of cases (70 of his own reported). The affected limb rests in a porcelain basin filled with a 2 per cent. solution of a lithium salt, with enough lithium hydrate to alkalinize it. The positive electrode is placed in the solution, and a large indifferent negative electrode is applied over the lumbar region. Guilloz gradually turns on a current of 150 or 200 ma., and allows this to flow for twenty or thirty minutes. He terminates the session by fifteen minutes' high-frequency autoconduction. Treatments are given every day or perhaps twice a day.

The results are relief of the local symptoms, a rapid reduction in weight, a cure of the attack, and prophylaxis against other attacks. Gouty deposits often disappear. It must be remembered that these are extraordinarily heavy currents, to be applied for such a length of time, and the usual care must be taken to prevent shocks or burns.

Bipolar high-frequency effluviation may be substituted for autoconduction in the above technic. Electric-light baths are of very great value in some cases where cataphoresis and high-frequency currents cannot be applied.

Bordier has found uric acid in the solution with which the positive electrode was wet during lithium cataphoresis. Dipping the arm in a solution of a salt of lithium, which forms the anode, lithium will be carried into the system by the current, and will appear in the urine. The cathode should be used if it is desired to introduce the acid radicle.

The best solution for medication with lithium ions is a 2 per cent.

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[1] Journ. des Practiciens, February 9, 1907.

[2] Journ. de Physiotherapie, September 15, 1904.

solution of lithium chlorid, with about $\frac{2}{1000}$ of lithium hydrate, just enough to render the solution alkaline.

Uric acid is a great many times more soluble in a solution of a lithium salt than in the normal fluids of the body, and this is the theory of this application.

Salicylic Ionization in Acute Rheumatism.—A 4 per cent. solution of sodium salicylate may be used to moisten the negative electrode, and a current of from 5 to 15 ma., depending upon the size of the electrode, may be applied for half an hour to an hour. Bordet[1] reports the cure of a case of talalgia by three treatments; of a case of tendinous articular rheumatism by ten treatments; of a case of acute muscular rheumatism by seven treatments; and of a case of acute polyarticular rheumatism by nine treatments.

Salicylic Ionization in Migraine of the Arthritic Diathesis.—According to Hartenberg,[2] an attack of sick headache in these cases is due to arterial spasm, probably from irritation of the cervical sympathetic, and this he considers due to a rheumatic infiltration of the tissues, especially the muscles of the neck. Parts of the muscles are swollen and tender. If the swelling is recent and subacute, it is elastic and supple, but if it is inveterate, there are hard nodules in the muscles. There may also be indurated glands, thickening, and infiltration of the skin. This condition irritates the superior cervical ganglion of the sympathetic, which becomes sensitive to pressure. Electrotherapy, which removes these infiltrations, cures the sick headaches.

Salicylic ionization is employed. The negative electrode is placed around the neck, and is moistened with a 20 per cent. solution of sodium salicylate. The positive electrode is at some indifferent place. A current of from 15 to 50 ma., according to the size of the electrodes, is allowed to flow for one-half hour. Recent muscular swellings disappear in twenty treatments. The harder ones take a longer time, but disappear with the glandular and cutaneous infiltrations. The sick headaches are benefited during the first month, and are cured, but occasional treatments are desirable to prevent relapse.

Salicylic Ionization for Muscular Rheumatism in the Lumbar Region.—Each electrode measures 6 by 8 inches and the negative electrode is wet with a 4 per cent. solution of sodium salicylate, and placed at the seat of the greatest pain. The other electrode is placed a few inches away, either above or below. A current of from 50 to 80 ma. is gradually turned on, and allowed to flow for from fifteen to sixty minutes.

Salicylic Ionization for Sacrovertebral and Sacrococcygeal Arthritis.—This has been successfully employed by Bordet[3] in cases of such severity that the patient was confined to bed. The negative electrode is wet with a 4 per cent. solution of sodium salicylate, and is applied over the painful articulation, while the other electrode is at a point near the spine, a few inches higher. A current of 30 or 40 ma. for about twenty minutes every day is required, and each treatment may be terminated by faradization with a fine wire coil and a moderate strength of current applied by a roller electrode.

Salicylic Ionization for Tic Douloureux.—This has been used by

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[1] Arch. des laborat. des Hôpit. d'Alger., June, 1906, No. iv, p. 135.

[2] Presse medicale, January 15, 1906.

[3] Bulletin officiel de la Societe francaise d'electrotherapie, January, 1906.

Leduc[1] and others with a certain proportion of cures. The negative electrode is a sheet of metal conformed to the shape of the portion of the face affected, and covered with absorbent cotton wet with a solution of sodium salicylate. A current of about 20 ma. is allowed to flow for about an hour. The process is the reverse of oataphoresis, the ions desired being the acid ions which flow away from the cathode, and not toward it. The indifferent electrode must be a large one to prevent irritation from such a strength of current for so long a time. One or more of the cells of a four-cell bath serve admirably as the indifferent electrode.

INDICATIONS FOR IONTOPHORESIS (*Machado's Table*).[2]

Skin Affections	Ulcers.	Salicylic iontophoresis. Zinc iontophoresis.
	Secondary infections of eczema or other secreting dermatoses.	Zinc iontophoresis. Cathode of amalgamated zinc.
	Sluggish wounds.	
	Epitheliomata.	
	Acne.	Requires a general anesthetic, and x-ray is better.
	Furuncle and anthrax.	
	Alopecia areata.	
	Falling of hair.	Zinc iontophoresis.
	Sycosis.	Copper iontophoresis.
	Tinea.	Copper iontophoresis.
	Fistulæ.	Magnesium iontophoresis.
	Verruga.	
Articular affections	Gout. Rheumatism.	Salicylic iontophoresis. Iodin iontophoresis. Electrolytic baths. Cl. Am., Cl Li. KI, $Na_2S_2O_3$ iontophoresis.
	Blennorrhagic rheumatism. Fibrous anchylosis.	Salicylic iontophoresis. Iodin iontophoresis.
Neuralgia		Quinin iontophoresis. Euquinin iontophoresis. Cocain and guaiacol iontophoresis. Salicylic iontophoresis.
Fistula ani		Zinc anode iontophoresis.
Genito-urinary diseases	Blennorrhagic urethritis, zinc anode iontophoresis. Blennorrhagic urethritis, gelatin bougie anode impregnated with nitrate of silver.	Iodin iontophoresis.
Glandular affections	Non-suppurative adenitis. Suppurative adenitis injection of KI solution, with evacuated sac and then galvanic current.	
Dental fistulæ		Copper iontophoresis.
Middle-ear disorders	Anode solution 2 to 5 per cent. NaCl, KCl, or KI. Cathode solution 2 to 5 per cent. pilocarpin nitrate.	

Ionic Medication by Means of High-frequency Currents.—An electrode for this purpose (Fig. 278) consists of a dome-shaped unipolar vacuum tube with a leading-in wire, which terminates less than an inch from the flat surface which is to be applied to the body. This leading-in wire is connected with the Oudin resonator or with one pole of the

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[1] Arch. d'Elec. med., November 10, 1905.

[2] Virgilio Machado, Les Applications, etc.

d'Arsonval transformer. In the latter case the patient holds a metallic electrode connected with the other pole. The flat surface has a recess in which is fixed a sheet of asbestos moistened with the medicine to be employed. There is certainly some effect upon the skin from the vaporization of the medicine by the shower of sparks employed, but it seems extremely doubtful whether any effective amount of the medicine is carried into the tissues by the currents. High-frequency currents are alternating, and one of the primary conditions of cataphoresis, electrolysis, and polarization is a unidirectional character to the current. When one wishes to prevent electrolysis and the like, the first step taken is always to make the current an alternating one. The effect of iodin upon the skin is, however, very much increased by this application.

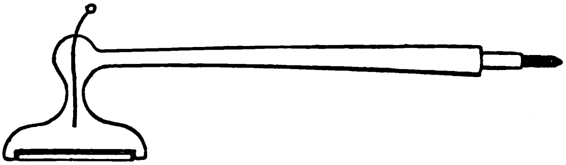

Fig. 278.—Electrode for ionic medication by means of high-frequency currents.

Chlorin Iontophoresis in Rheumatoid Arthritis.—Where there is a boggy swelling around the joint wrap joint with twenty thicknesses of lint wet with a sterile 2 per cent. salt solution. Tin-foil and oiled silk are outside of this, which forms the negative galvanic electrode. The positive indifferent electrode should have a larger area. The density of the current should be not more than 1 ma. per square centimeter. This is applied thirty minutes three times a week. It may free the ankylosis.[1] A finger-ring should not be worn because of possible concentration of the current; in fact, Humphris reports a burn under a finger-ring from 25 ma. for thirty minutes.

Various Opinions as to the Value of Electric Ionic Medication.—Zimmern[2] believes that there is nothing but a surface effect from the ions of medicinal substances which are used to moisten the electrodes, and that the deep effects, beneficial or otherwise, are due to the current itself. The last clause means, of course, the tissue ions which transmit the current, and which in reality constitute the current.

Iscovesco and Matza[3] have performed experiments in which they tested the electrolytic introduction of medicinal substances into gelatin containing $\frac{6}{10}$ per cent. common salt, and found only a surface action with potassium permanganate. A layer was produced upon the surface which prevented further progress of the colored particles. The result with copper sulphate was the formation of copper chlorid, which penetrated into the gelatin at the rate of 1 cm. (0.4 inch) in several hours. The result with iron acetate was the same as that with potassium permanganate.

Their conclusion is that it would be more effective to give a hypodermic injection of the substance to be introduced into the living body than to use the electrolytic method.

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[1] A Caries, Thèse de Bordeaux, January, 1905.

[2] Ninth Medical Congress, Paris, October 14, 1907.

[3] Physiological Laboratory of the Sorbonne, Comptes rendus de la Societè de biologie, February 8, 1907.

Tuffier and Mautè have experimented with salicylic ionization, and have obtained the characeristic color reactions in the most superficial layers of the epidermis, but never in the subcutaneous cellular tissue.

Latteux and Zimmern[1] have seen particles of copper deposited at the surface of the uterine mucous membrane in a rabbit, but never in the deeper tissues.

Gautrelet (December 25, 1907), in testing the effect of different metallic ions upon the heart in frogs, drew the conclusion that, under the usual conditions of electrolytic medication in man, the ions which are introduced form combinations with other ions, and produce a local effect, but do not enter the general circulation.

Frogs were placed with one hind foot in a solution of potassium chlorid, iron chlorid, magnesium chlorid, etc., and the other hind foot in a 2 per cent. solution of sodium chlorid, while a current of 2 ma. was allowed to flow. The metallic solution was connected with the positive pole. The movements of the denuded heart were registered by a Marey's cardiograph.

His conclusions were that potassium, mercury, and copper ions are essential poisons to the heart muscle, acting only slightly upon the cardiac nerves. Magnesium ions stop the heart's action by an effect upon its nerves. Trivalent iron ions slightly paralyze the heart muscles, but act as a violent poison upon the nervous system. Divalent iron ions and calcium ions are tonics of the cardiac muscles, but in large doses act as a nerve poison. Sodium and silver ions do not produce much effect, although the first slightly stimulates the myocardium, and the latter stimulates the cardiac nerves.

Brésard[2] has not succeeded in the ionic treatment of ankylosis of the large joints, even if of traumatic origin. He does not believe that the medicinal substance is carried beyond the follicles in the skin, and thinks that whatever effect is obtained in joint cases is due to the electric current and not to substances used to moisten the electrodes.

Just as the effect of basic or cations is manifested at the positive pole, so the acid or anions produce their effect at the negative pole. The solution of common salt, sodium chlorid, which is often employed to moisten the electrodes for ordinary therapeutic and diagnostic purposes, becomes dissociated into sodions and chlorions; the latter are acid ions or anions, and produce their effect upon the tissues close to the negative pole from which they start on their paths toward the positive pole. Nascent chlorin is responsible for part of the irritation produced when sodium chlorid solution is used to moisten the electrodes, and which may be prevented by the use of sodium bicarbonate solution for that purpose.

Electrolysis in Cancer.—Tumors of any considerable size require powerful currents applied with the same precautions as described under the head of Mercuric Cataphoresis (p. 393), the only difference being that platinum needles are usually employed, and that it has been customary to avoid the possibility of shock by using both poles actively. By this method the positive and negative electrodes are thrust into the flesh near the periphery of the tumor, and a current of 30 to 80 ma. is gradually turned on. This bipolar method does not secure the dry sterilized slough obtained when the different needles are all connected

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[1] Arch. d'Elect. med., November 10, 1907.

[2] Second International Congress of Physiotherapy, Rome, October 13, 1907.

with the positive wire, and the indifferent negative electrode is a large one of kaolin or clay. A general anesthetic is required. The entire area destroyed comes away. There is no selective action upon diseased tissues. The healthy tissues are destroyed as well as the morbid. There is no effect beyond the area through which the current flows in its greatest concentration.

The Strength of Current to be Employed in Electrolysis.—The effect is greatest upon the portion of tissue directly in contact with the electrode. With moderate currents it varies with the length of time during which the current flows and the current density, and depends, therefore, upon the quantity of electricity per unit of surface of contact. Electrolysis for stricture of the urethra requires the application of a sufficient quantity of negative electricity to produce interstitial softening of the tissues without destruction and sloughing. The proper amount is about $\frac{1}{2}$ coulomb per square centimeter of metallic contact at the negative electrode, and a current for about five minutes. The strength of the current will vary from 5 to 30 ma., depending upon the size of the electrode. The current for the cure of nevus by electrolysis without destruction of tissue should not exceed about 20 ma. per inch of length of positive needle in electric contact with the tissues for about five minutes. A greater strength will produce sloughing. Twelve to twenty galvanic cells in series will supply the necessary current for treating nevus, but as they may very quickly run down, a storage-battery or an arrangement for utilizing the direct electric-lighting current is preferable.

In these and other cases the current density is almost exactly proportional to the voltage, and if this is maintained at a uniform figure, it does not matter so much whether a larger or a smaller surface of the electrode is in contact with the tissues. If large galvanic cells are used, the voltage will be practically constant, and will depend upon the number of cells in series, each cell yielding an electromotive force of about $1\frac{75}{100}$ volts. The same is true of a storage-battery, but each cell in series yields about 2 volts. Using either twelve large galvanic cells or ten storage-cells in series, or arranging the table for utilizing the electric-light current in such a way as to yield 18 volts, a suitable current would be obtained for the treatment of nevus by bipolar galvanopuncture, while a considerably greater number of cells would be required if the monopolar method was used, and an indifferent sponge electrode was applied to the surface of the skin. In the treatment of superfluous hair the voltage again is the important thing, and is usually found to be 6 or 8 volts. The proper voltage is secured by adjusting the apparatus in the treatment of the first hair-follicle, and then there is no further regulation of the current while different hair-follicles on the same part of the face are under treatment. The same number of galvanic cells or of storage-cells, or the same adjustment of the volt controller and rheostat, will give the same current density, though the varying depths of the different follicles will allow of different areas of contact, and the milliamperemeter will indicate a different current strength. The same effect is produced over a larger or a smaller surface when the voltage is constant, and the milliamperage varies in consequence of variations in the area of contact.

It would be wrong to select a certain number of milliamperes and apply that strength to every hair-follicle, varying the voltage to overcome differences in resistance due to inequalities in the area of contact. The same number of milliamperes passed through half the area of contact would have twice the current density, and would produce a much more severe effect.

The milliamperemeter is the only measuring instrument required, although a voltmeter in addition would, of course, give direct readings of voltage, and would, therefore, be very convenient. The regulation of the strength of the current is effected by a cell-selector, and perhaps a rheostat and volt-controller in the case of galvanic or storage-cells, and by a volt-controller and rheostat when the direct electric-light current is used. The milliamperemeter shows whether all the connections are right, and a current of the proper direction and about the proper strength is flowing. A simple voltmeter may be improvised by connecting the two conducting cords with a 16-candle-power electric-light bulb, and noting the number of milliamperes registered by the milliamperemeter. We know that 250 ma. require a voltage of 110, and so in a rough way the number of volts is one-half the number of milliamperes which the battery will drive through a 16-candle-power incandescent lamp. The electrodes are not connected with the patient during the measurement. Having once adjusted the apparatus for the proper voltage, it is easy to keep it there or to reproduce the same adjustment.

Strength of Current for Deep Electrolysis.—The diffusion of the current from a small area of contact with the electrode is so great that no current which can be borne by the skin where the current density is greatest will produce much direct effect upon a deeply seated organ where the current density is least. A reflex effect is often obtained, and is frequently very beneficial. The skin over a deeply seated organ is often reflexly connected with it. The means for producing a direct effect consists in using extremely large electrodes, covering the whole joint or other organ to be treated. Two objects are accomplished: the lines of radiation traverse the deeper parts in abundance, perhaps even giving a greater current density at the center than at any part of the surface, and the large area of surface contact permits of the passage of very heavy currents without undue current density. A deep-seated organ may in this way be traversed by currents as strong as those ordinarily applied to the skin. Here again the proper current density at the surface in contact with the electrode is very important, and it is secured by proper regulation of the voltage.

The current density is usually not more than 1 or 2 milliamperes per square inch of surface of the smallest electrode for a continuous application unless it is desired to produce an electrolytic effect. If this is the case, a smaller electrode may be used for the active electrode, but the indifferent electrode should be large enough to comply with this rule. The indifferent electrode, for instance, has to be of an area of over 100 square inches when a current of 250 ma. is used for the cataphoretic or electrolytic destruction of a cancer of the breast by monopolar galvano-puncture.

Electrolysis for Hypertrichosis.—A fine iridoplatinum needle is connected with the negative pole of the battery. The positive electrode is a wet sponge electrode the insulated handle of which is held by the patient, who makes and breaks contact by pressing the palm of the hand against the sponge. This enables the operator to have both hands free, for support upon the patient's face, and to hold the handle of the needle (Fig. 279). Before the current is turned on the needle is introduced into a hair-follicle, catheterizing the follicle to its very bottom. Then the volt-controller and the rheostat are turned on so as to allow a current of from 2 to 5 ma. to flow. After five to twenty seconds the patient is told to let go of the sponge gradually and the current ceases to flow. Another hair-follicle not too near the first is then catheterized, and the patient told gradually to press her hand upon the sponge. The rheostat is not changed for each hair, but when passing to another part of the face which may be more sensitive, it is well to reduce the current to zero before catheterizing the first hair. The exact length of time that the current is to be allowed to flow is not to be measured by the clock, but by the effect. A little foam forms around the needle and sometimes a little redness. The hair should come away without any traction when seized by epilation forceps. It requires some little practice and judgment to destroy the hair-follicles without undue scarring. Even an expert will have to count on 20 per cent. of the hair returning. Scarring cannot be avoided entirely, but it is very much less if successive treatments are two days apart and if no follicles very near together are treated at the same séance. Too long or too strong an application will cause bad pitting, almost like that of small-pox. As the removal of a complete beard requires the destruction of 10,000 to 20,000 hairs of large or small size, and as it is impracticable to remove more than twenty to fifty at a sitting, the tediousness of this method of treatment is self-evident. The removal of a few large coarse hairs scattered among the fine lanugo hairs is a less staggering proposition, and so is the removal of a few coarse hairs situated at the corners of the mouth. But even

Fig. 279.—Electrolysis for hypertrichosis.

these may involve a course of treatment extending over a year or two. After all the hairs which it is desired to destroy have been removed, a certain number are bound to return, and others which were not removed seem to become coarse and require removal. The patient should return after two or three months, and everything objectionable should be removed. This has to be done over and over again, and will eventually succeed.

If a steel needle is used, especial care must be taken to make sure that it is connected with the negative electrode. Positive electrolysis with a steel needle would produce indelible staining of the skin.

Needles with a bulbous instead of a sharp-pointed extremity are recommended by Humphris ("Electrotherapeutics for the Practitioner"), who also recommends that hairs which are not loosened by a safe current should be forcibly pulled out. They will certainly return, but then may be destroyed. Rubbing some black substance over the surface may make the hair-follicles easier to find.

Electrolysis in Lymphangioma.—The technic is the same as for angioma cavernosa.

Electrolysis for Angioma Cavernosa.—Monopolar galvanopuncture may be performed with one or several (as in Fig. 280) iridoplatinum needles, varnished except at the point, and connected with the positive pole, while the indifferent electrode is made of a flat metallic ring covered with felt and surrounding the region to be treated. A current of 20 or 25 ma. for about five minutes is required.

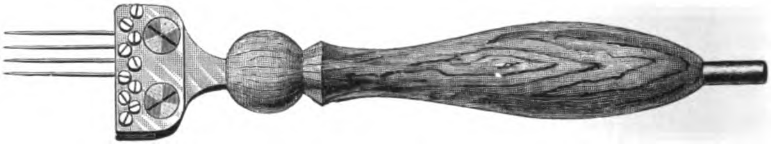

Fig. 280.—Instrument for multiple galvanopuncture.

The monopolar method is used only in special cases, where there is danger to blood-vessels or nerves from the bipolar method.

Bipolar galvanopuncture employs insulated needles connected with each pole of the source of continuous current. A current of 30 or 40 ma. is gradually turned on and allowed to run for about five minutes and gradually turned off. Several bipolar punctures may be made at the same session. The positive needle requires a little twisting to remove it, but the negative needle is usually perfectly loose.

Whichever method is employed, treatments should be given twice a week until the tumor feels like a hard, solid mass.

Electrolysis of small vascular tumors is accomplished by the use of a fine gold needle coated with shellac, except at its point. This is to be the anode, and an acid is liberated there, causing coagulation necrosis. For intra-uterine electrolysis a platinum stem 4 or 5 mm. in diameter serves as the anode, or it may be made of carbon. This disengages an acid and ozone, and cauterizes and disinfects the uterine cavity.

In a few cases the cathode is used, and the cauterization is by bases.

Electrolysis for Vascular Nevi.—Flat nevi with visible telangiectasis are readily cured by electrolysis, and if very small, the galvanopuncture may be monopolar (Fig. 281). The positive electrode is the active one, and the negative sponge electrode is applied to some indifferent spot. A current of 3 or 4 ma. is applied for about five minutes. If the skin turns white around the needle, it is time to stop, as further application will cause destruction of tissue. Larger flat nevi are usually treated by bipolar galvanopuncture. The positive needle is kept in one position at the middle of the nevus, and the negative needle is thrust first into one adenoid vessel and then into another until several have been treated at the same session. The treatments had better be given once a week; from 20 to 40 ma. are required, and an application of about five minutes. The current should be gradually turned on after the needles are in position, and should be reduced to zero before they are taken out. The negative needle becomes very loose, and care must be taken not to allow it to slip out and break the circuit. With a current of this strength a disagreeable shock would ensue.

Large nevi are best treated by the bipolar method, the needles being thrust in for ½ inch or more and being parallel with each other and with the surface. The idea is to cause the vascular tumor to be traversed by a current of uniform strength at all parts. Too marked an effect upon the tissues would cause sloughing, and this is not at all necessary in order to effect a cure. The appearance of lividity or blackening of the tissues indicates too long or too severe an application.

Fig. 281.—Method of performing electrolysis for vascular nevi.

Port-wine Stains.—The electrolytic treatment of these birthmarks is accomplished by the bipolar method. The positive needle is thrust into a certain part of the port-wine stain rather near the periphery, and a series of punctures are made around it with the negative needle.

Several such positive punctures surrounded by a circle of negative punctures are required. These should be far enough apart to prevent confluence of the superficial sloughs. The current should be of a strength of from 20 to 40 ma., and the usual precautions are taken to prevent shock. The results are not so uniformly satisfactory in the treatment of port-wine stains as in the treatment of the smaller nevi.

The Liquid-air Treatment of Port-wine Stains.—This has been used successfully by Pusey. He uses the snow or frost formed by exposing liquid air in an open vessel. This intensely cold, white, powdery mass is spread lightly over the port-wine stain. As it gradually disappears in the form of ordinary air, intense but superficial freezing of the tissues takes place. This is followed by a superficial slough, and in cases which he has reported the improvement in appearance has been very marked indeed. Carbonic acid snow is used in the same way.

The Treatment of Port-wine Stains by X-ray.—This means of treatment is considered on p. 1071.

Electrolysis for Hairy and Pigmented Nevi.—One method of treatment is by electrolysis of each of the different hair-follicles, using the same technic as for hypertrichosis, and this usually causes a sufficient disappearance of the entire nevus. If an additional treatment is required, the base of the nevus may be transfixed by two or more negative needles parallel with each other and with the surface, while the positive electrode is held in the hand. The current sufficient for the first part of the treatment for the destruction of hair-follicles should be from 2 to 5 ma., while for the second part of the treatment a current of from 20 to 30 ma. is required.

The *x*-ray may be found preferable when the hairy nevus is very large and all the hairs are very coarse and strong.

Electrolysis for Warts.—Negative monopolar galvanopuncture or bipolar galvanopuncture with a current of 20 to 30 ma. destroys these growths.

Treatment by the *x*-ray or by the application of radium is somewhat to be preferred, and high-frequency sparks are wonderfully effective.

Electrolysis in Acne and Acne Rosacea.—Large comedones may be treated by the same technic that is used for hypertrichosis. Hypertrophy of the nose requires electrolytic treatment of the different follicles, and after the subsidence of inflammatory reaction, may be treated by unipolar negative galvanopuncture. The current for the first part of the treatment should be of a strength of about 5 ma., while for the second part about 20 ma. are required. The results obtained are very good indeed, but, of course, the method must be applied with great care to prevent scarring.

By another method, the electrolytic needle is applied for acne with a current of 2 to 4 ma. for three to five minutes, ignoring the anemia, which occurs in a few seconds.[1]

Angiokeratosis and **tattoo-marks** are treated in the same way. Electrolysis is of doubtful utility in lupus erythematosus.

Sycosis is sometimes treated by an electrode wet with 2 per cent. solution of corrosive sublimate, applying a rhythmically reversed current for fifty minutes, or better, several shorter treatments. This is suitable for chronic cases with mixed infection; crusts are to be removed before applying the current and a little vaselin applied afterward (Meissonier). Most cases of sycosis are, however, to be treated with the *x*-ray.

Furunculosis is successfully treated by cataphoresis with a solution of corrosive sublimate or of zinc sulphate.

Meissonier has tried cataphoresis with ergotin with encouraging results in acne rosacea of the nose and cheeks.

The itching of **lichen ruber** is relieved by quinin cataphoresis.

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[1] P. Meissonier, in Boruttau.

Phagedenic chancre may be treated by corrosive sublimate cataphoresis.

For cocain cataphoresis a 5 or 10 per cent. solution is applied for ten or fifteen minutes and the anesthesia lasts thirty minutes.

Dermatitis papillaris capillitii may be treated by the negative galvanic needle, but the *x*-ray has given much better results in some cases under the author's observation.

Electrolysis for Sebaceous Cysts.—If excision cannot be performed, the cyst may be destroyed by galvanopuncture. The positive electrode is so arranged as to surround the cyst at a distance of ½ inch from it. The uninsulated needle connected with the negative pole of the battery is thrust into the middle of the cyst, and a current of from 8 to 10 ma. is applied for two or three minutes. The needle is then removed, and occlusive dressings are applied; two or three days later an insulated needle is thrust through the slough, so as just to reach the wall of the cyst, and a negative current of about 10 ma. is again applied. Three days later it may be found practicable to express the entire softened mass through the little opening which is left by the removal of the cutaneous slough.

Electrolysis for Keloid.—Negative monopolar galvanopuncture current of about 5 or 6 ma. may be employed.

Electrolysis for Warts.—Pedunculated warts are treated by thrusting the negative needle through the wart at a distance from the skin. A current of 2 to 4 ma. is allowed to flow for perhaps two to five minutes, until the wart has seemed to become blanched and looks like an herpetic bulla. This is rather painful, and it is better to use ethyl chlorid as an anesthetic. A steel needle can be used perfectly well. The same method may be used even if the wart is sessile. The author's patients greatly prefer the high-frequency spark.

Electrolysis for Nasal Polypi.—Negative monopolar or bipolar electrolysis may be applied with a current of about 20 ma.

Electrolysis for Ozena.—This must be done under local anesthesia. A pure copper needle connected with positive pole is thrust into the middle turbinated bone, and a steel needle connected with the negative pole is thrust into the inferior turbinated bone. The needles should be about $\frac{1}{25}$ inch in diameter, and should penetrate about 1 inch of tissue. A current of from 10 to 15 ma. is gradually turned on, and allowed to flow for about ten minutes. It is then gradually turned off and reversed for a short time in order to loosen the positive needle.

Electrolysis for Nasal Deviations and Spurs.—Bipolar galvanopuncture of the convex surface with a current of about 20 ma. for ten minutes is very effective.

Electrolysis for Dilated Blood-vessels in the Skin of the Nose.—This condition requires many separate galvanopunctures of the different blood-vessels at a considerable number of sessions. The treatment of a case may extend over as much as a year. Strikingly good results are often obtained.

Electrolysis in Vegetative Conjunctivitis or Spring Catarrh.—Cocain and adrenalin are necessary to secure complete local anesthesia, and if the patient is restless, perhaps a general anesthetic will be required. The indifferent electrode (positive, usually, but it makes little difference) is applied to the forehead or cheek. The other electrode is a platinum needle which is thrust into the different vegetations as close to their base as possible, and parallel with the surface of the conjunctiva. Possibly several may be transfixed at the same time. Flat vegetations are treated by scarification with the same needle held perpendicular to the surface. A current of from 2 to 8 ma. is used—not more than 5 ma. if cocain alone is used. Stronger currents cause pain and lacrimation.

Pansier[1] has used this technic successfully.

Electrolysis in Macroglossia.—When this is due to the presence of lymphatic cysts in the substance of the tongue, repeated bipolar electrolysis under an anesthetic will effect a cure. The technic is the same as for angioma cavernosa (p. 406).

Electrolysis in diseases of the Vulva.—Vegetations may be treated by galvanopuncture, bipolar or monopolar, and with a current of about 5 ma.

Chronic folliculitis vulvæ may be treated by positive galvanopuncture with much the same technic that is used for hypertrichosis (p. 404). A current of 2 to 5 ma. is applied for five to twenty seconds.

Electrolysis in Urethral Stricture.—*Fort's method of linear electrolysis* by means of a negative electrode shaped very much like a urethrotome, and acting somewhat like the blade of a galvanocautery, is generally regarded as dangerous and undesirable. A current of from 15 to 50 ma. is used. The indifferent electrode is placed upon the abdomen.

Newman's method of circular electrolysis is safe and effective, and is one of the methods of choice. The negative electrode is the active one, and consists of one of Newman's olivary urethral bougies, the next size larger than the smallest stricture. While the electrode is pressed lightly against the stricture, a current of from 3 to 10 ma. is gradually turned on—just enough to cause a sensation of warmth and prickling. About twenty minutes application may be required, and then this stricture may be found passable by a larger olivary electrode which may be used to treat another larger stricture. The indifferent electrode is held on the abdomen. Too great an effect is not sought at each session—perhaps an increase of only one or two numbers of the French scale in the diameter of each stricture. The treatments are given at intervals of a week or two. Dilatation by ordinary sounds is used in connection with Newman's electrolytic treatment.

Electrolytic dilatation is the name given to a method in which mechanic dilatation is the principal factor, though the dilating sound also carries a current of negative electricity. The dilatation may be *slow*, introducing a urethral sound which is large enough to pass through the stricture with a little stretching, and allowing a current of from 5 to 30 ma. to flow for five minutes or less. The treatments are given once a week. The indifferent electrode is a large one placed over the abdomen. All but a certain portion of the metallic sound is insulated by varnish. The strength of the current and the length of time for which it is applied bear an important relation to the amount of surface provided for the electric contact. The proper quantity of electricity for each square centimeter of electric contact is about $\frac{6}{10}$ coulomb, or the amount of electricity transported by a current of 2 ma. in five minutes. Calculating the area of exposed metal surface in contact with the urethral mucous membrane, and multiplying the number of square centimeters by 2, will give the number of milliamperes of current which should be applied

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[1] Arch. d'electricite med., September 25, 1905.

for five minutes. This will be from 5 to 30 ma., depending upon the size of the sound and the length exposed.

The *rapid method* of electrolytic dilatation uses the same strength of current, but a sound about five numbers (French) larger than the size of the stricture. Firm pressure is applied, and the sound passes through the stricture in a few minutes. Two or three different sizes are used at each session, and the treatments are given once a week.

Electrolysis for Esophageal Stricture.—*Fort's method* of linear electrolysis is dangerous because of risk of injury to neighboring organs.

Circular electrolysis is perfectly safe, and is performed with an olivary metallic electrode adjusted upon a flexible stem, which extends 2 or 3 inches beyond the electrode, and which contains an insulated wire. The whole forms an olivary esophageal bougie. This is connected with the negative pole, while the indifferent positive electrode may be held in the patient's hand. A current of 4 or 5 ma. should be gradually turned on while the olivary bougie is pressed gently against the face of the stricture, and in a few minutes the olivary bougie, which should be the smallest one which would not pass the stricture, now goes through readily. Sometimes the next higher number also may be made to penetrate freely at the same séance. Treatments should be given about once a week, and the method is not applicable to obstruction from pressure, as by tumors and aneurysms.

Electrolysis in Stricture of the Lacrimal Duct.—A Bowman's sound, insulated by varnish except at its extremity, is connected with the negative pole, while a positive electrode is held in the hand. A current of about 3 to 4 ma. is applied for three minutes once a week.

EXAMPLES OF GALVANIC, FARADIC, AND SINUSOIDAL ELECTROTHERAPY

THERAPEUTIC EFFECTS OF GALVANIC, FARADIC, AND SINUSOIDAL CURRENTS.[1]

General stimulating	Galvanism.	Cathodal closure. Alternating galvanic currents with or without condensers. Prolonged cathodal application (catelectrotonus).
	Faradism, galvano-faradism.	Successive discharges of the induced break current. Successive discharges of the primary current at the moment of opening of the circuit. Sinusoidal current. Short waves from a small condenser.
Excitomotor	Alternating galvanic currents with or without condensers. Cathodal closure. Faradism, especially with a short secondary winding (rhythmic or isolated waves, or sinusoidal). Galvanofaradism.	
Excitosensory	Same as for excitomotor, especially faradism, with a long secondary winding and rapid interruption.	
Excitosecretory	Galvanism. Faradism.	Applied to glands which are sufficiently accessible to receive a strong current.
Revulsive, derivative, decongestive, and combating irritation or fluxion	Faradism with long secondary winding and applied by metal brush. Galvanofaradism applied by metal brush.	
Vasoconstrictive	Faradism with short secondary winding.	
Vasodilative (hypotensive)	A secondary effect from vasoconstrictive applications. Faradism with long secondary winding. Triple phase or sinusoidal currents in hydro-electric bath.	
Resolving, antiphlygistic and stimulating the absorption of inflammatory exudates.	Revulsive and vasodilative applications. Heat applied in various ways. Compressed air-douche heated by electricity.	
Sclerolytic	Galvanism. Galvanism with ionization = iontophoresis.	
Excitonutritive and general or local tonic	General faradization.	Hydrofaradic or hydrosinusoidal baths.
	Rhythmic general faradization.	
	General galvanization. (Hydrogalvanic baths.)	
	Central galvanization.	Cerebral. Medullary.
	Galvanization with frequent interruptions with or without condensers.	
	Galvanization of cervical sympathetic.	
	Variations of an electromagnetic field.	

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[1] Modified from Virgilio Machado's table, Les Application, etc., Lisbon, 1912.

Stimulating the natural means of defense of the organism	Hydrogalvanofaradic and hydrosinusoidal baths.
Sedative or calmative, inhibitive, analgesic, or antispasmodic	Galvanism (prolonged anodal application). Galvanism (Leduc currents). Hydrogalvanic baths (prolonged). Hydrogalvanic enemata, etc. Undulatory faradization with wet electrodes. Monodic faradization (Stas). Sinusoidal faradization. Secondary effect of revulsive applications. Variations of an electromagnetic field. Douche of air heated by electricity. Iontophoresis. Quinin. Iontophoresis. Euquinin. Iontophoresis. Salicylic. Iontophoresis. Radium, etc.
Hypnotic	Hydrosinusoidal baths in insomnia due to circulatory disorders. Leduc currents (experimentally).
Coagulant	Anodal galvanism (by electrolysis). Heat produced by electric means.
Antiseptic	Prolonged anodal galvanism. Iontophoresis (copper, zinc, silver, etc.) by electrodes, wet with a solution of salts of these metals or by electrodes of the metals themselves.
Destructive of abnormal tissues	Electrochemical or electrolytic. Electrothermic. Galvanocautery. Electrothermic. Douche of air heated very hot by electricity.

Not included in this list, but considered in other sections of the book, are the *stimulating* effects of the static electricity, high-frequency currents, electric light, and electric heat; also the *excitomotor* effects of static disruptive applications and static wave currents and undulatory discharges of high-frequency currents; also the *excitosensitive* effect of high-frequency sparks, which are preferable to static sparks for this purpose, and the *diaphoretic* effect of electric-light baths and dark heat baths (Dowsing method); the *revulsive* effects, etc., of static sparks, high-frequency currents, electric light, electric heat, diathermy by high-frequency currents; the *vasoconstrictive effect* of high-frequency resonator sparks and energetic effluviation by high-frequency or static electricity; the *vasodilative* and *hypotensive* effect of high-frequency currents, and the electric arc bath and other luminous heat baths; the the *resolving, etc.*, effect of static wave currents, high-frequency currents from vacuum electrodes, electric heat and light locally and as a bath, diathermy by high-frequency currents, Röntgen rays; the *sclerolytic* effect of electric light and diathermy by high-frequency currents; the *excitonutritive, etc.*, effect of convective and conductive static applications, autocondensation and autoconduction by high-frequency currents, Tesla undulatory high-frequency currents, rhythmic effluve with Tesla-Thomson high-frequency apparatus, general electric-light bath, inhalations of ionized air; also *stimulating the means of defense* by high-frequency autocondensation and autoconduction, conductive and convective static applications, electric-light bath, ultraviolet rays, diathermy; the *sedative, etc.*, effects from conductive applications of static electricity, high-frequency effluve, Röntgen rays, blue electric light, ultraviolet rays, electric heat, dark or light, diathermy; also *hypnotic* *effects* from static baths; also *coagulant* effects from fulguration; also *antiseptic* effects from light, ultraviolet rays, high-frequency effluve, static breeze; *destructive* effects from electrothermy by the de Forest cold cautery; diathermy and electrocoagulation, cauterizing arc of the Tesla-Thomson high-frequency apparatus, high-frequency resonator spark (fulguration), and the *destructive* effect of concentrated light, Röntgen rays; also the *modification of the blood* by Röntgen rays, useful in leukemia, pseudoleukemia, etc.

GENERAL INDICATIONS FOR THE EFFECTS OF GALVANIC, FARADIC, AND SINUSOIDAL CURRENTS (*Machado's Table*).

Excitomotor	Curable central paralyses. Curable peripheral paralyses and pareses. Atony or myasthenia of striped and unstriped muscles.	
Excitosensitive and excitosensorial.	Curable central paralyses of sensation and hyperesthesia and anesthesia. Curable peripheral paralyses of sensation and hyperesthesia and anesthesia.	
Excitosecretory	Lacteal, seminal, etc., hyposecretion.	
Vasoconstrictive	Erythema, pruritus, etc.	
Vasodilative	Especially in cases of high arterial tension.	
Revulsive, derivative, counterirritant, and counterfluxionary.	Inflammations in the stage of resolution. Arthritis, especially blennorrhagic, metritis. Mucomembranous colitis, myelitis, neuritis, phlebitis, etc. Rheumatism, edema, hydrarthrosis, sprains.	
Sclerolytic	Fibrinous anchylosis, pleuritic adhesions, etc.	
Excitonutritive and tonic	Bradytrophia, especially arthritism, showing itself as gout, diabetes, obesity, etc. Neurasthenia with depressed nutrition. Convalescence from prolonged illness, especially if infective. Varicose ulcers, muscular atrophies, trophoneuroses of the skin.	
Sedative in general	Sydenham's chorea. Hysteria of hyperexcitable type.	
Analgesic	Neuralgias produced by curable lesions. Neuralgias of a toxic infection of dyscrasic origin. Hypersthenic dyspepsia, gastralgia with hyperchlorhydria, lumbago.	
Antispasmodic	Contractures and cramps in certain neuroses. Intestinal spasm in enteroneuroses, etc.	
Coagulant of the blood	Aneurysm. Angioma. Nevus.	
Stimulating the natural means of defense of the organism.	Tuberculosis of a slow type. Arthritic toxemia. Infection and auto-intoxication.	
Antiseptic or germicide	Various dermatoses. Wounds, ulcerations, etc.	
Destructive of abnormal tissues.	Traumatic gangrene. Diabetic gangrene. Lupus, etc.	
Atrophic	Adenitis. Glandular tumors. Fibromata and other neoplasms.	Röntgen rays chiefly indicated.

Gonorrheal Rheumatism and Galvanic Currents.—Billinkin[1] cured a case of blennorrhagic arthritis of the wrist by heavy galvanic currents.

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[1] Bulletin officiel de la Société Française d'électrotherapie, June, 1905.

The case was at a most acute stage, the wrist measuring 2 inches more in circumference than the other, and being stiff and painful. It had begun to be painful five days previously. Each electrode consisted of a sheet of metal 7 by 10 inches in size, with a very thick layer of wet absorbent cotton. The negative electrode covered the hand, wrist, and three-quarters of the forearm while the patient was seated upon the positive electrode. A current of 120 ma. was applied for fifteen minutes each day, and was followed by immediate relief and a permanent cure in four or five days.

Delherm's method is to apply a continuous current of 60 to 100 ma. for from thirty to sixty minutes. Large electrodes are placed at the two sides of the joint. It should be commenced at the beginning in the acute inflammatory febrile stage. There is relief from the very start. The pain, fever, and swelling disappear. Ankylosis is prevented when the treatment is begun at this early stage. At later stages the treatment is not quite so effective, but still does a great deal of good.

Heavy Galvanic Currents in Acute Gout and Rheumatism.—A current of 110 ma. may be applied for twenty minutes from a large positive electrode on the dorsum and a large negative electrode on the sole of the foot. A five-minute application of sinusoidal currents of a strength of 15 ma. is a desirable termination to the treatment. Billinkin[1] reports the cure of such an attack in two treatments.

A current of 50 to 80 ma. from two large electrodes applied to the knee in a case of acute rheumatism of that joint effected a cure in three or four days.

Electromechanotherapy (p. 468) is of value in some cases of chronic articular rheumatism, because of the increased respiratory exchanges produced by electric exercise.[2]

Faradic Currents in Hydrarthrosis of the Knee.—*Planet's method* is to stimulate all the different muscles of the thigh in succession, keeping one electrode at the upper and outer part of the thigh, and applying the other to the different motor points in succession for twenty seconds. This part of the treatment is very painful. The electrodes are then applied at either side of the patella for five minutes. The claim is made that a cure is effected in a few days without immobilization, and that there is immediate benefit. The objection is the pain.

Danger of Galvanic Currents in Tubercular Arthritis.—The current is to be cautiously applied in tubercular arthritis and in a patient who has tuberculosis of any other organ.

Faradic and Galvanic Currents for Hydrarthrosis.—Strong galvanic currents applied from large electrodes covering both sides of the joint have been considered the method of choice, but the author has used the milder high-frequency currents with success (p. 563).

A faradic coil with fine wire and rapid interruptions, and as strong a current as can be tolerated, may be used in the treatment of hydrarthrosis. This, however, is a painful method.

Rheumatoid Arthritis.—Faradization of the muscles about a joint affected with rheumatoid arthritis prevents muscular atrophy and relieves pain.

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[1] Bulletin officiel de la Société Française d'électrotherapie, April, 1907.

[2] C. R. Acad. des Sciences, cliii, 129, July 10, 1911.

ELECTROTHERAPEUTIC INDICATIONS IN SKIN DISEASES.

(Virgilio Machado's Classification.)

Stimulating			Falling of the hair, alopecia, atonic ulcers, scleroderma.
Sedative			Pruriginous dermatoses (lichen, prurigo, eczema, herpes zoster.
Vasoconstrictive			Erythemata.
Resolving and stimulating the absorption of exudates			Edemata following contusions.
Tonic and trophic			Dermatoses due to general nutritive disturbance. Localized trophoneurotic dermatoses.
Disinfectant			Septic wounds, ulcers.
Atrophic or Destructive.	*Electrolytic*		Elephantiasis, certain varieties of eczema, nævi, angiomata, hypertrichosis, alopecia areata, scleroderma, acne.
	Electrothermic	Galvanocautery. High-frequency sparks. Static sparks.	Lupus, certain varieties of epitheliomata, phagedenic ulcers, Röntgen-ray ulcers.[1]
		Compressed air heated by electricity.	Ulcers.
	Electrophototherapy.		Lupus, especially vulgaris or tubercular, certain epitheliomata; many superficial skin diseases.
	Röntgenotherapy		Epitheliomata, especially superficial, sarcoma, rodent ulcer, lupus,[2] elephantiasis, mycosis fungoides. Kerion celsi, acne rosacea, acne vulgaris, acne keloid, sycosis frambesiformis, Tinea favosa, onychomycosis favosa, trichophytina, lichen simplex, lichen ruber, and acuminatus. Sycosis, furunculosis nuchæ, microsporia, hypertrichosis, chronic eczema, seborrheic eczema, alopecia areata, nevus vascularis planus. Ichthyosis, pemphigus vegetans, psoriasis, neurodermatoses, scleroderma, pruritus, herpes zoster, herpes tonsurans, prurigo, trichorrhexis nodosa, scrofuloderma, hyperidrosis, verruca, verruca necrogenica (cutaneous tuberculosis).
Iontophoresis			*Ulcerations* (*salicylic or zinc iontophoresis*). Secondary infections from eczema and other secreting dermatoses. Epithelioma, acne, furuncle, fistula, carbuncle (zinc iontophoresis; anode of amalgamated zinc "requires a general anesthetic and has no advantage over x-ray"). *Alopecia areata* (*zinc or copper iontophoresis*). Falling of hair, sycosis, tinea, fistulæ, verruca (copper or magnesium iontophoresis).
Radium therapy			Nevus, small epithelioma, lupus, leukoplasia, acne rosacea. Keratosis, acne, eczema of a lichen type. Keloid, psoriasis, verruca.

Electricity in Skin Diseases.—Effluves from static or high-tension high-frequency apparatus are excellent for erysipelas and suppurating wounds and ecchymoses and contusions.

Scleroderma may be treated by central galvanization, and its localized forms, like morphea and Dupuytren's contraction, by local galvanic currents. For scleroderma circumscripta, two electrodes are at opposite

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[1] Machado says to "excise as early as possible; apply a plaster of fibrolysin to the indurated nodules, and that some radiologists have been cured by fulguration." Prevention is imperative (S. T.).

[2] "In lupus and other skin diseases, phototherapy is often associated with the x-rays, and both are sometimes aided by sensibilization of the skin with eosin or fluorescin.

sides of the area and a current of 8 ma. is applied for twenty-five minutes.

Chronic pruriginous eczema has been successfully treated by central galvanization, and so has *herpes zoster*. The same method of treatment of the spinal cord by either galvanic or faradic currents has given successful results in *vitiligo*, *ichthyosis*, *ecthyma*, *pemphigus*, *cutaneous gangrene*, *prurigo*, *eczema*, *urticaria*, and *lichen*, all these diseases being possibly of nervous origin. Hydro-electric baths are excellent in all these cases. The galvanic current locally relieves the itching of lichen ruber.

Perforating ulcer of the foot has been cured by faradization of the posterior tibial nerve, high-frequency currents (p. 563) also being useful, and *erythromelalgia* and *symmetric gangrene* have been successfully treated by the local application of galvanic currents.

Electrolysis in its applications to cutaneous lesions is referred to elsewhere (p. 409).

The resolving effect of the galvanic current makes heavy currents of this kind valuable in *keloid*, *mycosis fungoides*, *elephantiasis*, and in *cicatrices following burns*.

Alopecia is treated by faradization of the scalp. The author has had excellent results from the application of sponge electrodes, but has less confidence in the application of electric brushes and combs. The latter have their use, but it seems as if the combing and brushing could be better done separately from the application of the electric currents, and as if a sufficient strength of the latter to do much good is disagreeable or painful if applied by brushes or combs.

Static electricity is valuable in skin diseases, especially on account of the anesthetic effect of the static breeze or effluve upon such lesions as *pruritus*, *eczema*, and *lichen*. The general effect of a static bath is also excellent in these cases. The same effluves are valuable in *frostbite*, *radiodermatitis*, *psoriasis*, *impetigo*, *acne*, *lupus erythematodes*, and *furunculosis*.

Static sparks give good results in *keloid* and other *localized scleroderma* and *morphea*.

Static baths and effluves and sparks have been recommended for *alopecia*, but the author's experience with static electricity has led him to regard it as an application which is rather apt to cause the hair to fall out. The number of patients who have complained of this symptom in the course of a series of treatments by the static bath with an effluve applied over the head makes it seem as if it were not a mere coincidence. A number of static sparks applied to the scalp seem a better method for treating alopecia than several minutes' application of the static breeze.

Varicose ulcers and sluggish wounds may be stimulated by the application of static sparks, and the wound left after curettage for lupus may receive static sparks as a germicide.

Pruritus Vulvæ.—The best methods of treatment are by the *x*-ray and radium. Other valuable methods are the incandescent electric-light and the static breeze.

High-frequency Currents in Skin Diseases.—This is described on page 600.

Herpes Zoster—Treatment by Galvanic Currents at an Early Stage.—At an acute stage treatment may be applied by a positive electrode measuring 9 by 13 cm., applied along the spine at the level of the emergence of the nerve-roots, and by a negative electrode covering all the vesicles. A current of 6 to 8 ma. is applied for twenty-five or thirty minutes every other day. The disease is sometimes cured in forty-eight hours, and without leaving any subsequent neuralgia.

A *case of herpes zoster* occurring during a course of treatments by high-frequency currents was cured by Petit[1] by the application of heavy galvanic currents. A positive electrode measuring 15 by 16 cm. covered the posterior roots of the nerves in question, while a negative electrode of the same size covered the side of the chest and the three groups of vesicles. A current of from 60 to 70 ma. was gradually turned on, allowed to flow for ten or thirteen minutes, and gradually turned off. There was some relief from pain immediately, and a cure was effected by eight daily treatments.

Furuncles and Anthrax Treated by Galvanic Currents.—Negative galvanopuncture with a current of 5 or 10 ma. for five minutes is effective. It usually requires the use of ethyl chlorid for anesthesia. If a zinc needle is used, the positive wire should be connected with it to secure the benefit of zinc ionization.

X-ray in Skin Diseases.—This is of the greatest importance, and is referred to on p. 600.

Phototherapy, including treatment by the ultraviolet rays, is invaluable.

Obesity.—*Rapidly Interrupted Galvanic Currents.*—These currents have a powerful effect in slowing the development of growing and causing emaciation in adult animals. It may be that they will be found useful in the treatment of obesity.

Simultaneous Faradization and Vibration in Obesity.—One electrode is stationary upon some indifferent part of the body. The other wire from the faradic coil passes to the metal ball used as the vibrator, and the latter is covered with damp cloth. The current should be strong enough to tetanize the muscles. The coil has coarse wire.

Bergonié's Treatment of Obesity.[2]—A faradic coil, with a ratio of about 1 in the primary to about 3 in the secondary, is used, and the primary current is considerable, say 2½ amperes of 24 volts. The rate of interruption is about 30 per second. This current is rhythmically applied 100 times a minute by means of a metronome and after half the time it is turned off and reversed. Three electrodes pass from one pole to the back and the undersurfaces of the thighs. From the other pole wires pass to a number of rheostats, and through them to different large semicylindric electrodes back of the calves, front of the thighs, abdomen, and arms (twelve in all). These are held in place by rubber bracelets or by sand-bags all the way up to a total weight of 200 pounds. The current density is only .01 ma. per square centimeter. A hot wire milliamperemeter shows a total current of 25 to 30 ma. for an ordinary man, some fat and muscular women requiring 70 or 80 ma. Treatments last from twenty to forty-five minutes daily. Damp towels cover the electrodes and the patient has on a light dressing-gown. The best and most permanent rate of reduction is 2½ or 3½ pounds a week.

Cephalic Electrization with Heavy Galvanic Currents in Obesity.—This application has been found to produce a loss of weight, which is

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[1] Annales d'electrobiologie, April, 1906.

[2] Electrotherapeutics for Practitioner, Francis Howard Humphris, London: Longmans, Green & Co., 1913, p. 107.

so great as to make it a successful means for treating obesity, and to make it undesirable in cases of malnutrition, debility, or cachexia. The current must be applied in such a way as to avoid shocks or burns.

Raynaud's Disease.—*Treatment by Galvanic Currents.*—This is often successful, and consists in daily applications of half an hour's duration, and with a current of 10 to 20 ma. The positive plate electrode is placed at the nucha, and the limbs affected by the local asphyxia are placed in a negative bath.

Faradization in Chloroform Syncope.—A classic method has been the stimulation of the phrenic nerve in the neck, the other electrode being applied in the region of the diaphragm. The respiratory movements thus provoked are unilateral, and special electrodes are required for the nerve.

The method introduced by Villett[1] is a bilateral rhythmic stimulation of the pectoral muscles. The patient's arms are held behind his head, and the two electrodes are applied at the outer third of the two pectoral muscles. A deep inspiration is produced. On removing one of the electrodes expiration ensues, which may be assisted by pressure upon the sides of the chest. The stimulation is applied fifteen or twenty times during the first half-minute; later the stimulation is made at such times as to amplify the spontaneous movements of respiration.

Electricity in Incontinence of Urine.—Steavenson's method is to apply a constant current of 10 or 12 ma., with the anode at the perineum and the cathode in the lumbar region.

Guyon's method is to apply a faradic current by means of an electrode introduced so as to reach the sphincter vesicæ, the other electrode being at an indifferent region.

Bordier's method is to apply static induced currents by means of Guyon's sound. The patient is not insulated. The sound is introduced and connected with the external armature of one of the Leyden jars, and a series of short sparks is allowed to pass between the prime conductors of the static machine. Each shock is accompanied by a contraction of the sphincter. Treatments last five minutes and are not painful. Two applications a day are best at first; later, one application a day.

Marques[2] uses a little different method. He applies a cylindric negative electrode covered with wet cotton to the vulva and the urethral orifice in girls, or to the perineum in boys, while the positive electrode is applied over the hypogastrium. A constant current of 10 ma. is applied for ten minutes, and this is followed by two or three minutes' application of the same strength of current interrupted sixty times a minute by the metronome (the rhythmic rheotome used by the author, p. 474, is a simple device).

Isolated Induction Shocks for Incontinence of Urine.—Rockwell[3] believes that better results are obtained with these than with galvanic currents. One electrode is placed upon the abdomen or sacrum; the other is applied to the perineum in very young children, but better results are obtained when an olivary electrode can be introduced into the urethra and the current applied to the external sphincter. Separate

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[1] Presse med., September 13, 1905.
[2] Arch. d'elect. med., September 25, 1906.
[3] Medical News, December 9, 1905.

shocks from a faradic coil with coarse wire and a strong enough current to produce strong muscular contractions are applied at the rate of one to five per second. Daily applications of about five minutes are made at first, but later they need not be so frequent.

Spasm of the External Sphincter of the Urethra.—This may be treated by a rectal electrode, using a faradic current with very slow interruptions, coarse wire, and a very weak current; or the positive galvanic current or high-frequency currents. Static electricity is useful in neurasthenic cases.

Spasmodic Stricture of the Esophagus.—This condition is treated by faradization applied by means of an esophageal electrode, and one at some indifferent place. A series of currents may be applied to produce motions of deglutition, and in this way to relax spasm. A coarse wire coil and slow interruptions are used with a moderate strength of current.

Percutaneous Electrization in Gastric Diseases.—A considerable number of observers doubt the efficiency of intragastric electrization, and it is certainly difficult to apply, as well as disagreeable to the patient. By percutaneous electrization is meant the influence upon the stomach from electric applications made to the skin over that organ.

Secretory functions are best influenced by faradization. One electrode is stabile at some indifferent point, and the other is labile over the gastric area. A fine wire coil and rapid interruptions are used with the strength of current which proves most agreeable to the individual patient.

Motor functions are influenced by galvanofaradization, and the best way of applying it is by means of the rhythmic rheostat and pole changer described on p. 470. Quite large electrodes are used. One covers the gastric area, and the other is between the shoulder-blades. A galvanic current gradually begins to flow in one direction, and attains a strength of 20 ma., and then gradually diminishes to zero, and gradually attains a strength of 20 ma. in the opposite direction. The same changes take place in the faradic current, but the change in strength is more important than the change in polarity. The faradic coil should have coarse wire and slow vibrations, and the strength of the current should be such as to cause marked contraction of the abdominal muscles at the height of each wave of current. The oscillations of the current take place at the rate of from twenty to sixty a minute, depending upon the sensations of the patient.

Motor functions are also favorably influenced by the static induced current. The external armature of the Leyden jar at the positive pole is grounded, while the other is connected with a metallic electrode applied to the skin of the epigastric region. The patient is not insulated. The spark rods of the static machine are from 2 to 6 inches apart, and the machine is regulated to produce seven or eight sparks a second. Bordier makes the application to three principal points: (1) in the median line, a little above the umbilicus; (2) a couple of inches to the left of the median line and a little above the level of the umbilicus; (3) a little above the left anterior superior spine of the ilium. Strong visible contractions occur, and the patient feels a shock at each spark between the discharging rods of the static machine. The treatment lasts fifteen or twenty minutes, and is given every day or every other day. Dilatation of the stomach is cured in six weeks or so.

Sensory functions of the stomach are favorably influenced by galvanic currents, and surprisingly heavy currents, 100 or 200 ma., have been recommended by some authors.[1] Much weaker currents should generally be employed.

The Influence of Intragastric Electrization.—Freund[2] has made a series of observations from which he concludes that no specific secretion is excited, but that a thin, more or less acid mucous secretion takes place.

Atonic Dyspepsia.—This may be treated by intragastric rhythmic galvanic currents or galvanofaradization.

Galvanic Currents Applied to the Pneumogastric Nerve in Stomach Troubles.—An electrode may be applied over each pneumogastric nerve at the base of the neck, and a current of 5 or 10 ma. is applied for five minutes, with occasional reversals. This may cause the disappearance of nausea, vomiting, and regurgitations in cases of dyspepsia, with symptoms suggestive of cancer.

Electricity for Habitual Constipation and Membranous Colitis.—Slight cases yield to the static bath, static breeze, or static sparks in the iliac fossæ. The sparks are for the atonic, the breeze for the spasmodic, variety.

Grave cases of atonic constipation may be treated by faradization, rhythmically reversed galvanic currents, or the Morton wave current. These may be applied to the skin or to the skin and intestine.

Grave cases of spasmodic constipation and enterocolitis are greatly benefited by faradogalvanization. The galvanic current is about 100 ma., and is not interrupted or increased, the faradic current being a mild one from a coil of fine wire. One very large electrode is over the abdomen, and another is over the back.

Diarrhea yields to applications of glass vacuum electrodes from the Oudin resonator applied over the surface of the abdomen.

Faradization is also excellent; a very large electrode covers the abdomen, and another the lumbar region. The current is from the coil with large wire, and the interrupter is arranged to cause a rapid trembling of the abdominal muscles, not a tetanic contraction.

A *case of severe chronic colitis and dysentery* successfully treated by the *x*-ray and high-frequency currents from vacuum electrodes is described on p. 590.

Electric Intestinal Douches.—The stronger currents are useful in intestinal obstruction and occlusion and in lead colic. They are regarded as an emergency treatment, intended to provoke a movement of the bowels at any cost. They are not suitable for repeated application because they would produce spasmodic constipation.

A suitable instrument is a soft-rubber rectal tube, which covers the electrode and also transmits the liquid. No part of the metal comes in contact with the flesh. From 1 to 1½ pints of salt water is introduced. An electrode measuring about 5 by 6 inches is placed over the abdomen, and a constant current of about 30 or 40 ma. is gradually turned on. Then the current is suddenly reversed, and allowed to flow in the opposite direction for one or two minutes. These reversals and periods of constant flow are kept up for twenty or thirty minutes. The patient may then try to have a movement. This may

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[1] Rabinovici, Thèse de Paris, 1907.

[2] Arch. f. Pathol. u. Physiol., May, 1905.

take place at once, but the effect is sometimes delayed for several hours.

Torpor recti, a condition of chronic constipation with feces always present in the rectum, but failing to stimulate evacuation is successfully treated by electric douches with the external electrode sometimes over the sigmoid flexure and sometimes over the cecum. The current flows in the same direction for ten minutes before being gradually reversed.

The Apostoli Method for Uterine Fibromyoma.—The author of the method called it electrochemic cauterization of the mucous membrane, and the results he obtained were the production of a new and healthy mucous membrane, with a greatly reduced tendency to hemorrhage and often a reduction in the size of the fibroid tumor. He gave the present writer an opportunity to examine some of his cases in Paris in 1891. The tumors had become much smaller, and there was a symptomatic cure. Complete disappearance of uterine fibromyomata under this treatment occurs in only about 10 per cent. of the cases treated.

A galvanic current of 60 or 70 ma. is usually employed, but in certain cases as weak as 20 or 30 ma. or as strong a current as 100 ma. or more is used. The active positive electrode has a platinum or carbon olivary tip and an insulated stem. It is applied successively to all parts of the mucous membrane of the body of the uterus, but the internal os, the cervix, and the external os are protected to avoid the risk of cicatricial contraction. The indifferent negative electrode is usually a large clay or kaolin electrode placed over the abdomen. The application lasts about five minutes. Besides the electrolysis of the mucous membrane there is a trophic effect upon the tumor tending to cause a return to normal conditions. The latter effect is best obtained in intramural and submucous fibromyomata. Subperitoneal tumors are often very little affected by the current from an intra-uterine electrode. Galvanopuncture is suitable for some of these which are suprapubic or which can be reached through Douglas's cul-de-sac. Care is taken in each case to avoid coils of intestine and to apply the current exclusively in the substance of the uterus. The needles are to be insulated where they pierce the vagina or skin and the parietal and visceral peritoneum.

The Final Results of the Electric Treatment of Uterine Fibroma.—Massey[1] has traced the results for three years after treatment in 101 cases, among them were 18 cases in which the tumor had disappeared; 26 cases were failures.

Interstitial hemorrhagic fibroids are the most favorable, and the submucous variety also yields good results. The subserous variety, especially if pedunculated, are less certain. Fibroids complicated by pyosalpinx and other suppurative or inflammatory conditions are not entirely safe to treat in this way.

Electricity in Sterility Due to Atrophy or Imperfect Development of the Uterus.—Rhythmic undulatory galvanic currents with alternations, applied from an abdominal electrode and a vaginal or an intra-uterine electrode, and a maximum strength of 15 ma., are excellent. The author has had success also with high-frequency currents applied from a vaginal vacuum electrode with a double stem, which insulated all but the portion in contact with the cervix and Douglas's cul-de-sac.

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[1] Jour. Amer. Med. Assoc., May 21, 1904.

De Watteville or Faradogalvanic Currents for Menorrhagia and Enterocolitis.—A positive electrode is placed over the lumbar region, and a large negative one over the abdomen. The galvanic rheostat indicates 100 ma., and the faradic current is from a coil of fine wire. The application lasts about ten minutes.

Electric Treatment of Asthma.—The positive electrode is the active one, and measures 2½ inches in diameter. It is placed first on one side of the neck and then on the other; then at the side of the trachea, and then at the lower attachment of the sternomastoid. It is moistened with plain warm water. The negative electrode is a larger one, and is placed either at the nape of the neck or, in a case of tuberculous pseudo-asthma, it may be placed over the upper part of the lung in front of the chest. The strength of the current is from 10 to 15 ma., and may be rhythmically changed from zero up to this strength. This oscillation should take from five to six seconds. The treatments last from ten to fifteen minutes, and may be applied two or three times a week.

Expectorant Effect of Galvanic Currents.—The negative electrode is placed at the back of the neck, and the positive first on one side and then on the other, at the border of the scaleni; or the positive wire may be branched and lead to an electrode on each side of the neck. The current is to be 2 or 3 ma. with one anode, or 4 or 5 ma. with a double anode, and is to be a constant current for about three minutes.

Stembo[1] has found that this application will provoke cough and profuse expectoration where medicines fail. He has used it successfully in bronchitis and bronchopneumonia.

Ear Diseases.—*Stimulation of the Facial Nerve in the External Auditory Canal for Dry Otitis Media.*—Rhythmic faradization strong enough to cause contraction of all the facial muscles is supposed to exercise the muscle of the atrium, and consequently prevent ankylosis of the articulations of the ossicles. According to Bergonié and Roques,[2] this treatment often improves the hearing.

Rhythmic galvanization acts in the same way.

Simple Galvanic Currents in Ear Diseases.—The negative electrode is an olive electrode with a flexible insulated stem; it is passed through an Eustachian catheter into the middle ear. The positive electrode is applied at any indifferent place, such as the hand. A current of from 2 to 6 ma. is applied for five or ten minutes. It should be turned on and off gradually. Tubotympanitis at all stages and hyperplastic otitis, deafness, and roaring in the ears are greatly benefited. The treatment has some effect upon the auditory nerve and the cerebral centers. The occurrence of too much vertigo would be an indication for caution as to the strength of current.

Galvanofaradization in Lumbar Sprains.—A negative electrode measuring 3 by 5 inches is applied to the muscles of the lumbar region, and a similar one to the insertion of the glutei.

The galvanic current is 10 or 12 ma., and the faradic coil with fine wire is used.

Electric stimulation of the abdomen is useful in the treatment of arterial hypertension.[3]

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[1] Therapie der Gegenwart, 1904.

[2] Arch. d'electricite medicale, August 10, 1906.

[3] Doumer, Acad. des Sciences, Paris, August, 1912; Jour. Amer. Med. Assoc., September 14, 1912, p. 890.

Sinusoidal Currents for Dyspepsia.—Two wet electrodes, 6 by 4 inches, are fastened at either side of the umbilicus and the sinusoidal current (p. 426) is applied for fifteen or twenty minutes.

HYDRO-ELECTRIC BATHS

A. Baths which simply form the electrodes, as in the four-cell bath, require only a word at this place. The liquid may be a very weak solution of sodium chlorid with a small amount of glycerin added to prevent irritation of the skin at the surface of the liquid. If no such precaution is taken, a ring of redness is produced around the limb, at the junction of air and liquid. It is apparently due to oxidation. Wearing a stocking or a gauze bandage extending an inch or two above and below the level of the liquid will also prevent this irritation. Baths like these are employed principally as a very convenient means of supplying a perfect contact over a large area for the transmission of rather heavy currents, but not, as a rule, for the heaviest currents.

B. Single large baths (Fig. 282) in which both the electrodes dip into the liquid and in which the patient's body is immersed, cause the transmission of a part of the current through the patient, while about twice as large a part passes through the liquid from one pole to the other. The liquid may be plain warm water. The addition of a little sodium chlorid or sodium bicarbonate, or any other medicinal substance, increases the conductivity of the liquid and reduces the proportion of the current which passes through the patient. The electrodes had better be flat pieces of copper or carbon enclosed in a lattice work of china to prevent contact with the patient. The tub may be made of wood, glass, or porcelain, an ordinary metal-lined tub being unsuitable. There should be no metal outlet pipe connected with the ground—it should open in the air. The inlet pipes should not dip into the liquid. It

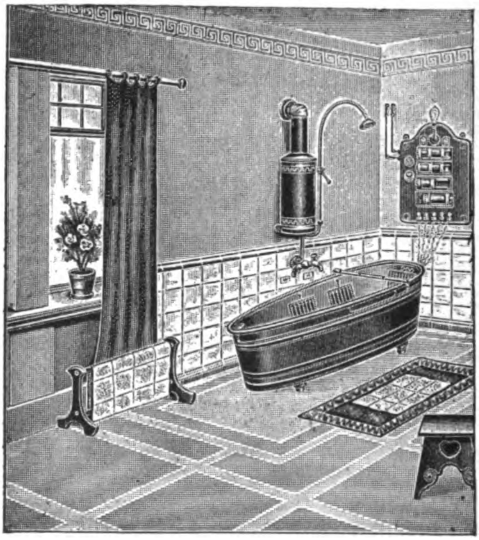

Fig. 282.—Hydro-electric bath.

should be possible to place the different protected electrodes close to the nucha, one or both shoulders, one or both hips, one or both knees, or the feet. Several electrodes of different sizes and shapes will be found useful.

The bath-tub may be made of perfectly enameled iron. There must be no bare spots of metal exposed to contact with the liquid; practically all the current would travel through the metal instead of the patient.

A wooden or enameled iron bath-tub has one advantage over stone or porcelain. The latter feels stone-cold to the patient wherever his flesh touches it, while the two former assume the temperature of the water.

A General Bath Divided by a Diaphragm (Fig. 283).—This is an expedient which is not apt to give much satisfaction. The idea is to have two portions of liquid separated by a partition with a hole through which the patient's body passes, but around which the partition is hermetically sealed. Electrodes dip into the two portions of liquid, and the entire strength of the current is supposed to pass through the patient's body.

It is sometimes desirable for the patient to hold one electrode, which may be a metal handle, laid across the bath-tub, and upon which his hands may rest. The other electrode, which may be single or multiple, dips into the water. It may be placed near any part which it is desired especially to affect.

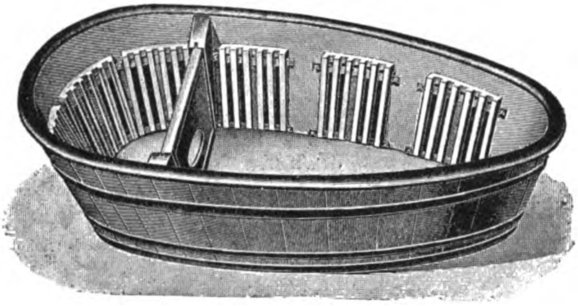

Fig. 283.—Tub for electrotherapeutic bath.

The switch-board for electric-bath currents should be so constructed that placing metal plugs in different holes will connect the cathode with any or all of the different electrodes, and the same way for the anode. For instance, the negative wire may be connected with the electrodes near both hips, and the positive wire with the bar electrode, on which both hands rest, or the negative wire may be connected with a single large electrode near the feet, and the positive with one near the shoulders.

A shovel electrode with an insulated handle is useful for localizing the current (Fig. 284). It is connected with one pole of the battery and can be held in the water close to any part of the body, while the other electrode rests in some other part of the water.

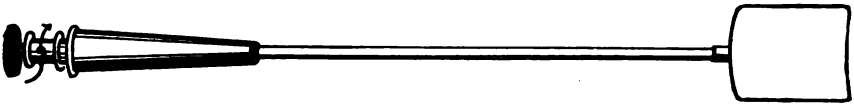

Fig. 284.—Shovel electrode for hydro-electric bath.

A milliamperemeter is required to measure currents up to 300 ma. for most ordinary purposes; and up to 2 amperes in a bipolar bath of tan-bark solution and other medicinal solutions. The electric resistance of these solutions is so small that a much larger fraction of the current will pass through the liquid, and a stronger total current is required in order to transmit the usual amount through the body of the patient. This does not apply, however, when the patient holds one electrode which is out of the bath-tub. Then all the current indicated by the milliamperemeter traverses the patient's body.

Faradic or Induced Currents for Electric Baths.—The ordinary faradic coil has too great resistance for this work, owing to the thousands of turns of fine wire through which the secondary current must pass. The necessary apparatus consists of a primary coil of coarse wire, with a vibrating or a pendulum interrupter. The discharge which is sent through the bath is of the same extra current that is utilized for lighting gas-jets by electricity. This is a current of self-induction in the primary coil. There is no secondary coil. A battery of three or four wet or dry cells is sufficient for this purpose, or a suitable strength of current may be derived from the direct electric-light circuit. The adjustment of the induced current is twofold: regulation of the number of turns utilized in the primary coil, and regulation of the position of the iron core. Drawing the latter out of the primary coil makes the induced current weaker, and alters its character, making it less harsh, just as in the case of a faradic coil.

Intermittent Claudication.—A case of this disease without any perceptible femoral pulse and long inability to walk was cured by W. Kuhn.[1] The faradic current was applied to both legs by a four-cell bath.

Currents Employed in General Hydro-electrotherapy.—Galvanic and faradic currents are largely employed.

Fig. 285.—Undulatory currents.

Sinusoidal, undulatory, and triple-phased currents are especially effective.

Undulatory Currents.—These are unidirectional, and increase and diminish in a regular curve (Fig. 285), similar to portions of a tracing made by a sinusoidal current. They are used in the same periodicity and strength as the sinusoidal currents, whose effects are also very similar.

Sinusoidal Currents.—The name is derived from the sinusoidal curve formed by a graphic record of the current. This resembles a semicircle above the zero line continued in a semicircle below that line. The current, therefore, is an alternating one with a gradual change of strength and direction. In the *Wappler sinusoidal apparatus*, one of the types employed by the author, the direct 110 volts electric-light current is reduced to a certain maximum limit by a volt controller and a rheostat, which are set stationary for each treatment. There is also a rheostat in the shape of a drum-shaped spiral of wire and an electric motor moves

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[1] Zentralblatt f. Chirurgie, April 26, 1913.

a contact back and forth along the drum. When the contact is at one extremity of the drum the fixed maximum current flows in one direction. As the contact moves along the drum the strength of the current gradually diminishes and at the middle point is of zero strength, and beyond that point the current begins to flow in the opposite direction and gradually attains the fixed maximum strength. A complete cycle would mean the time elapsing between the maximum flow in one direction and the next maximum flow in the same direction. For many purposes the author sets the maximum current at 15 or 20 or, possibly, 25 milliamperes, and each complete cycle occupied about five seconds. The current is applied through wet electrodes, usually by means of a four-cell bath, for ten or fifteen minutes. This may be called a slow sinusoidal current.

The *McIntosh polysine generator*, also in use in the author's office, employs power derived from the electric-light current. Either alternating or direct current is employed to run a small dynamo generating an alternating current of the sinusoidal type with a periodicity of from 12 to 1800 cycles a minute. The polysine generator also delivers different other types of current, including the direct galvanic current.

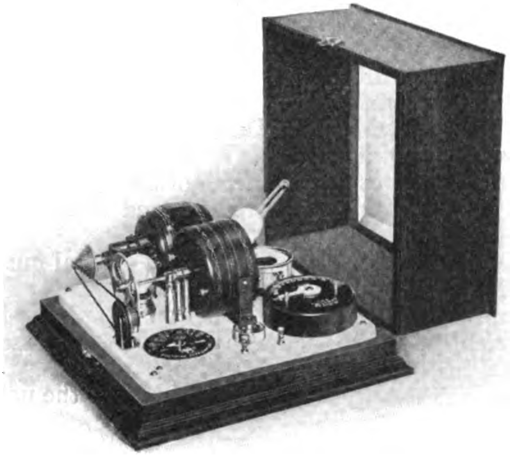

Fig. 286.—Polysine generator for sinusoidal, galvanic, and other currents.

The author finds the slow sinusoidal current preferable for a local effect upon muscles and nerves in paralysis, spastic conditions, and neuritis.

The rapid sinusoidal current is an exceedingly valuable therapeutic agent in heart disease, for which it is usually applied as a hydro-electric bath. Either a full bath or a four-cell bath may be employed according to whether or not the general effect of the full hot-water bath with or without carbonic acid gas is desirable. The benefit in heart disease is demonstrable not only in relief from oppression, but also in more natural sphygmographic and electrocardiographic tracings and other improved objective signs.

In any apparatus for hydro-electric baths it is absolutely essential that there shall be no direct connection of the patient, or the water in which he is placed, with the electric-light current. This would be dangerous in case of grounding through the water-pipes and elsewhere.

Smith, of Marbach on the Bodensee, is to be credited with the introduction of sinusoidal currents into therapeutics.

Strubel's "das Wechselstrombad" is a mine of information, not only in regard to his own use of the sinusoidal current, but of other recorded observations. It is the authority for many of the following statements:

Sinusoidal currents applied to muscles and motor nerves produce tetanic contraction, but each curve being a more gradual one requires a much greater strength of current than with faradism.

The patient experiences a sense of billowy waves in the whole muscular system, and these waves of contraction can be noticed if the hand is laid upon the patient.

There is a regulating effect upon the blood-pressure, reducing it in cases of hypertension and raising it in low arterial tension. Many different observers have corroborated Hornung's statement that a relaxed dilated heart may be found smaller after a sinusoidal bath. This is accompanied by increased cardiac efficiency and a higher blood-pressure of a beneficial character.

They do not, like hydrotherapy, dilate the superficial blood-vessels either immediately or later.

There is no angiospasm or marked blanching of the surface, such as occurs in a cold carbonic acid bath.

Lippert classifies the principal effects of sinusoidal currents as:

1. Generally raising the blood-pressure and slowing the pulse.
2. Decided increase in metabolism.
3. Exercise of the heart muscle and of the general muscular system.
4. Assisting the patient to sleep.

In a full bath it is estimated by Eulenburg that one-fourth to one-third of the current passes through the body. It all passes through the patient in a four-cell bath.

Arteriosclerosis is usually a contra-indication to the use of sinusoidal currents.

An extremely feeble heart is a contra-indication and so is coronary endarteritis.

Sinusoidal currents are especially indicated in uncomplicated insufficiency of the heart muscle, also even in the most severe cases following infectious, toxic conditions and overwork, heart disease, with commencing failure of compensation, chronic myocarditis, cardiac and vascular neuroses. According to Hornung, the faradic current is to be preferred in treating excitable patients with malnutrition, weakness, and anemia.

Hypertrophy of the left ventricle is generally not reduced, but irregular and rapid pulse and cardiac murmurs are greatly improved as well as all the subjective symptoms.

The four-cell bath, with a sinusoidal current of 20 to 30 ma. in the hands of Lossen, has given good results in neurasthenia, improving the feeling of apprehension, palpitation, appetite, digestion, sleep, and motor power. Excellent results were had in arthritis deformans, arthritis urica, chorea, muscular rheumatism, cerebral and peripheral paralyses, neuralgias, cramps, anesthesia, and paresthesias. The present author corroborates this from his own experience. Lossen secured improvement in locomotor ataxia, especially in the lightning pains, the disturbances of sensation, and to some extent in the ataxic gait. Lossen corroborates Von Noorden's observation of cases of diabetes in which the muscular pains and weakness, eczema, and insomnia were benefited.

The current for a full bath should always be gradually increased from zero to about 30 ma. and as gradually reduced at the end of the treatment. The electrodes had better all be the same size, 50 by 25 cm. (20 by 10 inches), and if a triple phase current is used the electrodes are near the nape of the neck, the feet, and the pelvis. Baedeker recommends that the temperature of the water shall be 90° F., and that first treatment of six or eight minutes, during which time a cool wet towel shall be laid on the patient's head, and that the current shall be followed by general massage or vibration. Baedeker has often noticed a temporary heart murmur after the treatment which was not audible before. The symptoms of valvular stenosis, asthmatic attacks and edema, and general muscular weakness are improved. Slight forms of aneurysm are benefited, severe forms are a contra-indication. High degrees of disturbance of compensation are a contra-indication.

Strubel's technic is to place the patient in a warm water bath of 95° or 97° F. without an electric current, and in two to five minutes there is usually a reduction of 20 or 30 mm. in blood-pressure from peripheral vasodilatation. Then a current of 10 or 20 or, at the most, 30 ma. is cautiously turned on. Now the arterial tension is seen to rise, the pressure in the auricles falls. This lessens the dyspnea of certain slight cardiac cases. Increasing the current to 25 or 30 ma. raises the blood-pressure to its original point. Gradually turning off the current causes a reduction in the blood-pressure, and in most cases it remains below the ordinary level for one-half to one hour. Strubel's work with hundreds of cardiac cases showed improvement in the electrocardiograph as well as in the ordinary objective and subjective symptoms. He considers the indications for sinusoidal current baths to be: (1) Neurasthenia, hysteria, hypochondriasis, and exhaustive conditions; (2) myocarditis; (3) valvular lesions; (4) exophthalmic goiter and other thyroid intoxications. It does not reduce the size of the thyroid gland, the possibility of toxemia, or of emaciation, but it does improve the pulse-rate, the insomnia, and the electrocardiogram; (5) selected cases of arteriosclerosis, characterized by the subjective symptoms of angina pectoris, cardiac asthma, mild or severe dyspnea, and the objective symptoms of increasing cardiac insufficiency, arrhythmia, marked changes in the form of the heart, and in the electrocardiogram. In such cases strophanthus, Marienbad water to drink, massage, and sinusoidal currents are wonderfully beneficial; (6) organic nerve diseases.

Laquer advises beginning the treatment of a neurasthenic patient, with secondary cardiac symptoms, at first with hydrotherapy and later to cautiously apply sinusoidal currents.

Physiologic Effects of General Hydrogalvanic Baths.—The patient may recline with a longitudinal electrode near the whole length of the spinal cord from the occiput to the lumbar region, and with the other electrode near the feet. A current of from 50 to 150 ma. is generally used in a bath containing about 100 quarts of plain water. According to Helley and Gaertner, about 25 per cent. of the current will traverse the body. Different sizes and shapes of baths and electrodes and different liquids produce variations from 4 per cent. for a bipolar bath to 50 per cent. the maximum, which occurs when the bath forms only one electrode, and the entire current enters the body. The nervous structures form the principal conducting paths for the current after it has passed through the skin.

Effects *regardless of polarity* are a sensation of warmth and a redness of the skin, especially near the electrode, but also more or less general.

Effects with the *negative dorsal electrode* and the positive electrode near the feet. There is an increase in general sensory and motor and reflex excitability, and often annoying tingling of the skin of the legs. Cerebral activity is stimulated, and in neurotic persons there may be irritability of temper and insomnia after a few treatments. Neurasthenic, hysteric, or insane patients are often unable to take this treatment, even with the weakest currents, and sometimes not even with the current polarity reversed. Patients suffering from conditions of depression experience a sense of almost immediate relief, and if there has been uncertainty of equilibration, this is recovered from after a few treatments. The pulse-rate is increased, especially if there has been bradycardia. There are increased amplitude of the pulse and increased arterial tension, especially in cases with hypotension. There are increased cerebral and sexual activity. Asthenopia and other functional disturbances of the cranial nerves are benefited.

Patients with weakness of the cardiac muscle from fatty degeneration or produced by valvular disease show immediate benefit after such a hydrogalvanic bath.

Multiple neuritis is certainly benefited, and so are anterior poliomyelitis and post-diphtheric paralysis. The arthritic diathesis is benefited, and medicinal substances are now often added to the water in these cases.

Effects with the Positive Pole at the Nucha and the Negative at the Feet.—The difference between this and the other polarity is in the direction of producing a sedative effect upon the nervous system, but this is not at all constant, and the excitability of the brain and medulla are not generally diminished.

The hydrogalvanic bath is used for obesity, but its benefit is not yet fully established. The treatment acts in this disease and in the arthritic diathesis by the production of nascent oxygen, and an increase in oxidation and all other tissue exchanges.

Galvanic Hydro-electric Baths in Sciatica.—This method of applying galvanic currents results in the cure of a large majority of the cases.

Hydro-electric Baths in the Lightning Pains of Locomotor Ataxia.—Balsamoff[1] secured relief in these cases by general galvanic baths, followed each time by an application with the current localized in the painful region.

Cell-baths and Their Effect with Galvanic Currents.—These are a specific for localized neuritis; the same strength or a greater strength of current may be used as if the electrode were not formed of a mass of liquid. The author's plan of having the patient wear a stocking or a gauze bandage prevents an irritation at the upper surface of the liquid —an effect of oxidation. Adding glycerin to the water has the same effect.

The addition of a medicinal substance enables one to secure a cata-

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[1] First Internat. Cong. of Physiotherapy, Liege, 1905.

phoretic effect. Schnee's four-cell bath (Figs. 287 and 288) or general galvanic baths succeed in the pains of locomotor ataxia, swelling of the legs, sciatic neuralgia, chronic muscular or articular rheumatism.

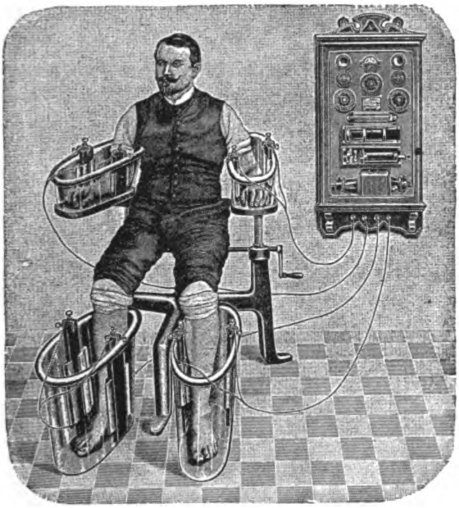

Fig. 287.—Schnee's four-cell bath.

In inveterate chronic articular rheumatism each galvanic bath may be followed by faradization of the spine.

The modification shown in Fig. 289 forms an excellent means of applying strong galvanic currents with safety and very great convenience. Rheumatism and a great many different nerve and joint affections are benefited by this treatment.

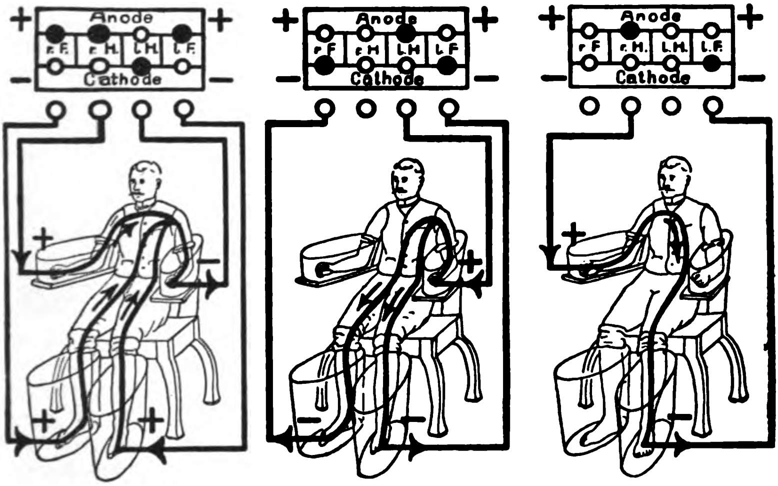

Fig. 288.—Various connections of four-cell bath.

A *sinusoidal four-cell bath* has a local effect which may be very valuable in the treatment of Raynaud's disease. Here the four-cell bath is excellent, acting by local vasodilatation. The current is an alternating one, and consequently both poles produce the same effect. Cell-baths, whether galvanic or otherwise, have less effect upon cardiac rhythm and arterial tension than a general bath with the same kind of current.

Cell-baths with Galvanic Currents in Neuritis and Muscular Atrophy of Traumatic Origin.—The arm or the leg is in a negative bath, while the positive electrode is applied between the shoulders. A current of 12 or 15 ma. may be applied for fifteen or twenty minutes every day.

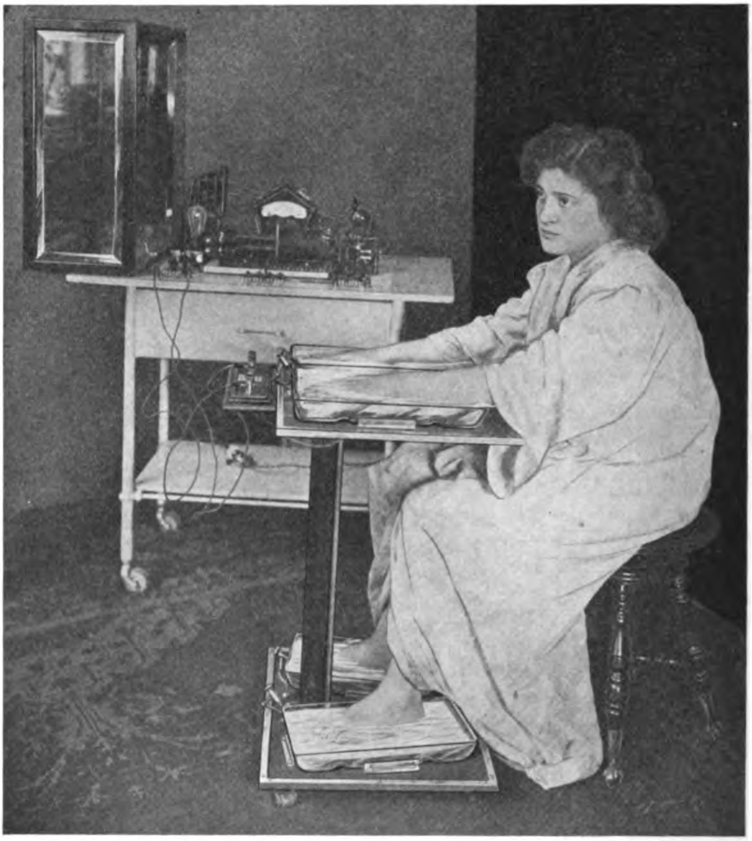

Fig. 289.—Treatment by four-cell bath and the author's electrotherapeutic table.

Hydro-electric Baths with Sinusoidal Currents.—Sinusoidal currents with a tension of about 30 volts, which have recently come into such prominence, are generally applied in this way, and with a rate of about twenty periods a second. As a general bath, these currents produce a marked effect upon cardiac action and blood-pressure, and have an important field in the treatment of cardiovascular disorders.

Hydro-electric baths with a sinusoidal current have an excellent effect in heart disease, including cardiac dilatation.

Raab[1] advises the use of a higher rate of alternation—14,000 instead of 5000 per minute—in order to avoid pruritus from sinusoidal hydro-electric baths. He also thinks it a mistake to treat cardiac cases from the start with sinusoidal currents exclusively. Their tension is 30 volts, and in some cases the faradic current with a tension of only 8 volts is preferable.

Lippert[2] has made 146 observations regarding these effects, and found that there is an increase in blood-pressure. It may be 10 or 15 mm. more after the bath than before. This may be accompanied by a reduced pulse-rate. There is a pronounced increase in tissue exchanges. Weakened and atrophic, cardiac, and other muscles are strengthened. Arteriosclerotic and neurasthenic patients who have suffered from insomnia are enabled to sleep.

These currents have a general tonic effect upon the tissues.

They are excellent in dermatoses dependent upon deficient tissue exchanges, such as inveterate pruriginous eczema and urticaria.

They are excellent in cases of paralysis of peripheral nerves, of considerable muscular atrophy, and of progressive muscular atrophy and similar conditions.

They are very soothing in cases of neuralgia and of muscular or articular pain.

Their effect in *renal colic* is excellent, and decided diuresis is provoked.

The effect of hydro-electric baths with sinusoidal currents in cardiovascular disease is decidedly different from that of triphase currents applied in the same way. Albert Weill and M. Mougeot[3] have made careful observations in a number of cases. The temperature of the bath was 34° to 35° C., and the patient remained in it for ten minutes before the currents were applied. Measurements were made of the arterial and capillary pressure before and after the simple immersion, and after every five minutes of application of the sinusoidal currents. The cardiac area was registered by the orthodiograph before and after the treatment. The radial pulse and the capillary pulse were recorded on a revolving cylinder at first in the simple bath, and again after twenty minutes of sinusoidal currents. The electrodes were immersed near the outer surface of the thigh, the left side of the back, and the right side of the front of the body.

Their results showed a marked increase in arterial tension, just the opposite from the effect of baths with triple-phase currents: little or no effect on capillary pressure; a change in the arterial pulse indicating that peripheral resistance was not reduced, but was even increased. If the pulse was dicrotic, this characteristic was diminished. An easily dilated heart was increased in size. A dilated hyposystolic heart may be reduced in size, but this change is much less certain than with triple-phase currents, which reduce peripheral resistance.

Their conclusion as to therapeutic indications is that hydro-electric baths with sinusoidal currents are useful in functional hypotension, or when it is present without cardiac lesions; also in mitral disease,

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[1] Rev. de therapeut., August 15, 1906.
[2] Berlin klin. Woch., April 25, 1904.
[3] Jour. de Physiotherapie, June 15, 1906.

when the cardiac muscle is still intact. If there is such a thing as producing a tonic effect upon the heart by a peripheral vasoconstriction, this is what the bath with a sinusoidal current does. This action would be contraindicated in uncompensated dilatation of the heart and in a variety of cardiovascular conditions, where the indication is to reduce the blood-pressure and the labor imposed upon the heart.

Margaret Cleaves has found that hydro-electric baths with sinusoidal currents give remarkable results in neuro-arthritic and cardiovascular diseases.

Kellogg has also demonstrated the same excellent results from baths with sinusoidal currents.

Cell-baths with Sinusoidal Currents.—These have an important application in gynecology, as sitz-baths.

Hydro-electric sitz-baths with a sinusoidal current of 2400 to 3000 periods a minute have an excellent effect upon menorrhagia due to fibroma, and also upon coccygodynia and hemorrhoids. Paull[1] has obtained subjective improvement without much objective change in suppuration of the adnexa and retroflexion of the uterus. The sitz-baths contain three electrodes—one in front, one behind, and one at the side, so that the current may be directed through the pelvis in different ways.

Sinusoidal cell baths are useful in all conditions for which a general sinusoidal bath is used if the condition is confined to one limb. Neuralgia, rheumatism, and gout are examples.

Hydro-electric Baths with Triple-phase Currents.—The source of current is a rotary transformer, actuated either by the direct or the alternating electric-light current, or by a battery of accumulators (storage-battery). In the latter case the battery should generate 12 volts. Three different wires leave the transformer at points equally distant, and each is traversed by an alternating current having the character called sinusoidal. These currents are not synchronous in the three different wires, but have a difference in time equal to one-third of a period. The regulation of the currents is best accomplished if the currents from the rotary transformer pass through the primary wires of three transformers, in which the secondary coils are at an adjustable distance from the primary, and consequently the induced triple-phase currents supplied to the three electrodes in the bath may be varied in strength.

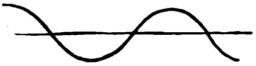

Fig. 290.—Sinusoidal current.

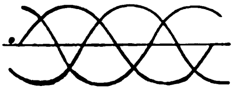

Fig. 291.—Triple-phase current.

About twenty periods a second is desirable for these currents, and 100 to 140 ma. is the usual strength of current in a general bath. The same periodicity, but a much weaker current, is suitable for use in a cell-bath or for ordinary electrodes with which the full strength of the current passes through the patient. In some general baths with medicated solutions, on the other hand, a much stronger current, such as 300 ma., is required, because a smaller fraction passes through the patient's body.

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[1] Zeitschrift g. diaet. u. physik. Therapie, vol. viii, November 1, 1905.

The physiologic effects are to excite a tingling of the skin, which is extremely disagreeable if the periodicity of the current is too rapid. The triphase current supplied by some industrial and electric-light circuits has a periodicity of about 2400 a minute, which is about twice as rapid as is desirable for therapeutic purposes. A rotary transformer is used to change this to a triphase current with a periodicity of about 1200 a minute. The more rapid periodicities also produce muscular contraction similar to what would occur from a general application of a strong faradic current, and this also disqualifies them for therapeutic use.

Triphase currents of the proper strength and periodicity for general baths produce capillary dilatation, increased metabolism in muscular and other tissues, and a reduction in blood-pressure. They are curative in peripheral paralysis, muscular atrophies, and progressive myopathies. Applied in moderate strength in cases of neuralgia and pains in the muscles and joints, they are soothing. They have a specific beneficial effect upon the heart, relieving dyspnea, irregular rhythm and palpitation, and high arterial tension. They are especially beneficial in the high arterial tension of uricemia, the menopause, commencing arteriosclerosis, aortic atheroma, simple or syphilitic. They fail only in pronounced cases of renal sclerosis.

Albert Weill and Mougeot[1] find changes in the form of the radial pulse tracing consisting in an increased amplitude of the systolic wave, an increase or a reappearance of the wave of arterial elasticity, an increase in dicrotism. They find no increase in the amplitude of the capillary pulse. They find a distinct reduction in the size of the heart if it has been dilated.

Cell Baths with Triple-phase Currents.—These are especially useful in Raynaud's disease and other local conditions of the circulatory disturbance, with capillary or arteriole constriction. They are valuable in neuritis and in joint lesions. They have an important application as four-cell baths in the treatment of rheumatism and lithiasis.

OZONE

Whenever an electric spark, whether powerful or almost imperceptible, passes through the air, ozone is produced by the action of ultraviolet radiations upon the oxygen of the air. This very active form of oxygen has marked effects upon living organisms, and it seems certain that a considerable part of the benefit derived from the application of static electricity or high-frequency currents is due to the absorption of this gas through the lungs or through the skin.

Its **effects** in a concentrated form are poisonous. Bacteria are killed, and even rabbits succumb in ten minutes if kept in an atmosphere containing 8 milligrams of ozone per liter. A therapeutic strength is at the most 1 to 3 milligrams per liter of air, and a single inhalation lasting ten minutes will increase the proportion of oxyhemoglobin if that is subnormal, and also the number of red blood-corpuscles. Another beneficial effect from a course of treatments is an increase in respiratory capacity and a reduction in white blood-cells if they are in excess.

It is **indicated** in some cases of anemia, pharyngitis, tonsillitis, and whooping-cough. It is used also as a general tonic in many debilitated states.

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[1] Jour. de Physiotherapie, May 15, 1906.

It is to be recommended in the strongest terms for use in a workroom or office where a large number of persons are employed, and where it is possible to secure good ventilation, but no sunlight. A desirable outfit may be obtained from the General Electric Company, and if kept in operation during business hours makes a wonderful difference in the health of the employes.

Method of Use.—The production of ozone by sparks of perceptible size is accompanied by the production of much nitric acid and other substances which unsuit the air for inhalation. It should, therefore, be obtained from the silent discharge which takes place from metallic points charged with very high-tension electricity and which forms an effluve. An ordinary whisk-broom connected with the terminal of an Oudin resonator and held near the patient's face is a simple and effective means of giving inhalations of ozone. Stronger inhalations are obtained by surrounding the Oudin resonator or the Guilleminot spiral by a glass jar through which air can be inhaled by the patient.

The ozone generator, shown in Fig. 292, has a leading-in wire to be connected with an Oudin resonator yielding a high-potential high-frequency current. The vacuum chamber thus charged is surrounded by an outer glass held in the patient's hand and separated from the charged glass by a space in which innumerable sparklets pass through the air with violet and ultraviolet rays. This changes a considerable portion of the enclosed air into ozone. The ozonized air is forced through this space and then bubbles through pineneedle oil, or some similar liquid, to absorb the nitrogen pentoxid before it is inhaled by the patient.

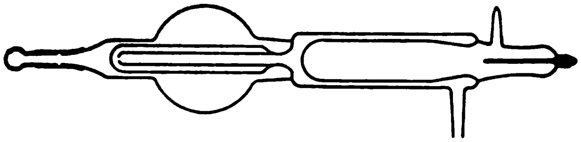

Fig. 292.—Ozone generator from high-frequency current.

The arrangement used by Albert Weill for ozone inhalations from a static machine is shown in Fig. 293. The discharging rods of the static machine are within a distance of an inch or two, so that a stream of powerful sparks passes between them. The outer coating of a Leyden jar whose inner armature is connected with the positive pole is grounded. From the outer coat of the negative Leyden jar a wire leads to an insulated metal rod which enters the ozonizing bulb, but does not touch its glass walls. A large part of the outside of the ozonizing bulb is coated with metal, and from this a wire passes to the earth. Air is driven through the ozonizing bulb and inhaled by the patient. A brush-discharge occurs between the metal rod and the glass wall of the ozonizing bulb, which fills the bulb with violet and ultraviolet light, the latter causing a profuse generation of ozone.

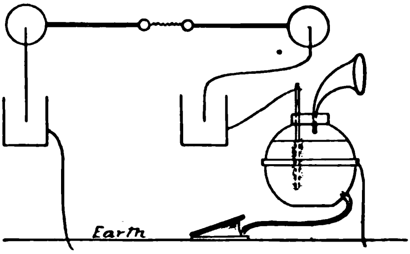

Fig. 293.—Diagram of apparatus for ozone inhalations.

Chany[1] **has made valuable observations upon the influence of voltage** on the formation of ozone.

To be perceptible at all, several thousand volts are required. The 50-cycle alternating electric-light current and a large Ruhmkorff coil is a most effective generator. The voltage at which ozone is perceptible is characterized by effluve. At 40 per cent. of this voltage the discharge is like a rain of fire. The power of ozone production is as the square of the difference in potential between the armatures of the ozonizing tube.

Thousands of Volts.	Ozone Production.
10.1	0.153
12.5	0.860
16.5	1.580
26.0	3.700
41.0	9.900

It is useless to go higher than the last figure, because the quantity of ozone then increases in simple proportion to the energy expended.

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[1] C. R. de l'Acad. des sciences, June 2, 1902.

PHYSIOLOGIC AND THERAPEUTIC EFFECTS OF ELECTROMAGNETS

So many excellent and entirely unbiased observers have tested the matter with magnets of every possible strength and without any discoverable effect, that the author feels that these instruments cannot at the present time be considered as being of practical value in therapeutics. He does not at all wish to be understood as thinking that prolonged exposure to a field in which such tremendous energy is operative is without some effect, and perhaps usually a deleterious effect, upon the human system. But it does not appear to have an effect which can be put to practical use. The subjective symptoms of a sensation of light and a feeling of pleasure or repulsion according to the polarity are liable to be partly of suggestive origin. It certainly produces no muscular or motor nerve effect. The beneficial effects which have sometimes occurred in tic douloureux, congenital myotonia, and different neuroses, are apt to be transitory and are possibly due to suggestion. Cases of facial neuralgia, intercostal neuralgia, alcoholic neuralgia, and nervous insomnia have sometimes shown very great improvement.

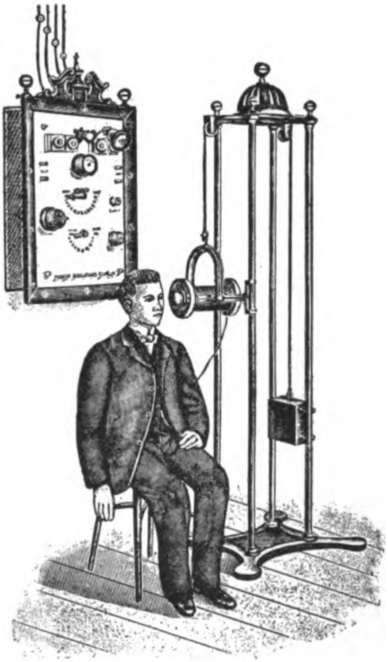

Fig. 294.—Therapeutic application of electromagnetism.

Technic.—The best technic appears to consist in the use of a current which is reversed about 100 times a second, and which is of low voltage but high amperage.

Outside of the rôle that they play in all kinds of coils, motors, and other apparatus, electromagnets have two distinct uses in medicine. One is the extraction of steel and iron particles, especially when embedded in the eye, and another is their application for a supposed effect upon the brain and other parts of the nervous system.

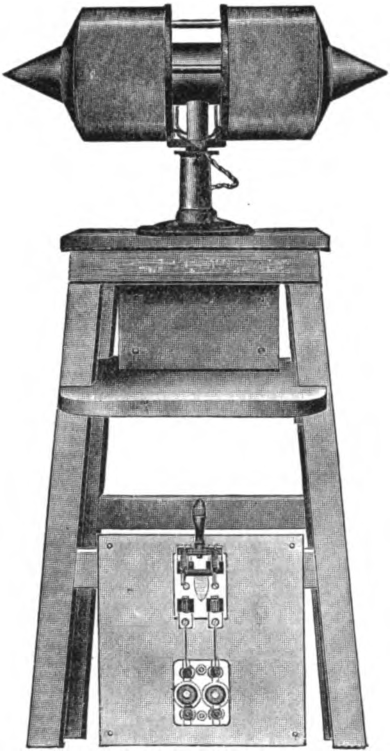

Fig. 295.—Electromagnet for removing bits of steel from the eye.

Electromagnets for Extracting Foreign Bodies from the Eye.—The electromagnet (Fig. 295) has a large, soft-iron core, terminating in a point to which sometimes different iron tips are attached. There is a distinct danger in employing tremendously large and powerful electromagnets which are capable of dragging a bit of steel or iron through the media of the eye and producing irreparable lacerations.

ELECTRICITY IN DISEASES OF THE NERVOUS SYSTEM

The general problems of electroneurophysiology have been treated elsewhere in this work, and the general relations of electricity to nervous irritability have been touched upon. In limiting, therefore, the consideration of the use of various forms of electric action to diagnosis and to treatment of diseases of the nervous system, it is with the tacit understanding that the present chapter concerns itself with the most practical of issues.

The applications of electricity in the diagnosis and treatment of diseases of the nervous system are increasing in number and in value every year; the introduction of newer currents is constantly widening the field, and with each new installment of scientific journals, new processes are described which often find a permanent place in nervous therapeutics. The following pages have been prepared to present the present-day aspect of what has been demonstrated to be of permanent value, as well as to endeavor to point out the merits of some of the more important of the later advances in the science of electrotherapeutics as applied to the disorders of the nervous system.

The topics to be discussed will be as follows:

(I) The use of electricity in diagnosis.
  (*a*) Diagnosis of disorders of peripheral nervous systems—motor and sensory.
  (*b*) Diagnosis of disorders of central nervous systems.
(II) The use of electricity in therapeutics.
  (*a*) Therapeutic applications of electricity in diseases of the peripheral nervous system.
  (*b*) Therapeutic applications of electricity in diseases of the neuromuscular apparatus—neuromuscular disorders.
  (*c*) Therapeutic applications of electricity in treatment of organic disease of the central nervous system.
  (*d*) Therapeutic applications of electricity in treatment of functional diseases of the central nervous system.
(III) Electric sleep and death due to electric currents.

DIAGNOSIS OF DISORDERS OF THE PERIPHERAL NERVOUS SYSTEM

Motor Reactions.—The principles of nerve stimulation and muscle reaction have been considered elsewhere at great length. There remains here to take up the specific applications of such teachings, particularizing on the subject of the reactions of the neuromuscular apparatus for diagnostic purposes.

It is to be recalled that when a galvanic current of sufficient strength is passed through a neuromuscular arc, it causes a contraction in the muscular portion of the arc, or in the particular muscle if the arc includes but one muscle. This contraction, as has already been seen, is not for the galvanic current a continuous reaction. It takes place only when—

(1) The current enters, *i. e.*, at current closing.
(2) The current stops, *i. e.*, at current opening.
(3) There is a sudden increase in force of current.
(4) There is a marked decrease in strength of current.
(5) The direction of the current is reversed, anode to cathode; cathode to anode.

Experimentation on lower animals has permitted the laying down of certain laws regulating the actions of the galvanic current—*i. e.*, Pflüger's laws, which have been discussed elsewhere in this volume. These laws have a limited application in human neuro-electric technics.

The laws of human normal muscle contraction then are for an intact nervous organization to be expressed as follows for weak, medium, and strong currents.

I. CClC, for weak currents (cathodal closure contraction only).
II. CClC, AClC, AOC, in order of activity for medium currents.
III. CClTet, AClC, AOC, CClC, for strong currents (cathodal closure tetanus, anodal closure contraction, etc.).

The strength of such currents has been accurately measured by Stintzing and Erb and a number of students. Stintzing has examined most of the muscles of the body, to determine the minimum amount of current that will cause a cathodal closure contraction, and has constructed tables which give the average values in the different muscles and nerves of the body. These tables are of great value for comparative purposes—his faradic tables are of little practical value for the average practitioner; his galvanic tables, however, are useful, and are here printed. It must be remembered that great variation exists in different nerve-trunks to the same strength of galvanic current. Such variation exists for differing ages, and have been made the subject of special researches of a very intricate and extensive nature by numerous experimenters—Mann,[1] Westphal, Thiemsch, and others.

STINTZING'S TABLE FOR GALVANIC SCALE OF NEUROMUSCULAR EXCITABILITY IN MILLIAMPERES.

	Lower Limit Value.	Upper Limit Value.	Average.
Nerves.	Ma.	Ma.	Ma.
1. Musculocutaneous	0.05	0.28	0.17
2. Spinal accessory	0.10	0.44	0.27
3. Ulnar	0.20	0.90	0.55
4. Peroneal	0.20	2.00	1.10
5. Median	0.30	1.50	0.90
6. Crural	0.40	1.70	1.05
7. Tibial	0.40	2.50	1.45
8. Mental	0.50	1.40	0.95
9. Ulnar	0.60	2.60	1.60
10. Zygomatic	0.80	2.00	1.40
11. Frontal	0.90	2.00	1.45
12. Radial	1.00	2.70	1.80
13. Facial	1.00	2.50	1.75

Method of Study for Disease of Neuromuscular Apparatus

When either a muscle or its motor nerve or the end-plates become disordered in their functions, certain electric changes are apt to take place. These occur in both their quantitative and qualitative reaction to faradic, galvanic, and special types of currents.

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[1] See Ludwig Mann, Arch. d'electricite médicale, 1903, for an extensive résumé of this work.

The qualitative changes, which are the more readily observed, consist in a change in the formula of contraction, or a modification in some particular of the normal formula.

Such variations may depend upon purely accidental modifications of contact, of saturation of electrodes, etc., but assuming the technic to be free from graver errors, these changes are dependent in large part on the more or less superficial seat of the nerve-fibers. Diffusion produces a certain amount of scattering for the deeper seated nerve-fibers, and thus only a part of the current registered by the galvanometer is utilized. Fat makes considerable variation, and, as has been noted, the age of the patient is of moment. This latter fact is of importance in determining the Erb reaction in children thought to be suffering from tetany, since very frequently much heavier currents are needed in infants and children.

Further modifications depend largely upon the rate of make and break in an interrupted (faradic) current. Tetanus usually results if the interruptions are over twenty a second. The introduction of the induction-coil, however, has caused a number of complications in the tests usually applied, since the discharges are usually irregular as to quantity and as to duration, and d'Arsonval has shown the great importance that is to be attached to the form of the wave of the electric impulse. This has led to the introduction of mechanic forms of making and breaking by Leduc, since a greater amount of regularity in making and breaking results than when the induction-coil is employed. They are further capable of more accurate mensuration. Leduc has shown that when the impulses have only a duration of about $\frac{1}{1000}$ second, and follow each other at the rate of 100 to the second, the best type of effect is produced. Thus Leduc's table is of interest in this connection:[1]

Duration of Impulse. Seconds.	E. M. F. Required to Produce Muscular Contraction. Volts.
0.00001	22.0
0.00010	15.0
0.00020	13.5
0.00030	12.0
0.00040	11.5
0.00050	10.5
0.00060	9.5
0.00070	9.0
0.00090	8.5
0.00100	7.0
0.00200	7.5
0.00300	8.0
0.00400	8.5
0.00500	9.0
0.00600	9.5
0.00700	10.0
0.00800	11.0
0.00900	12.0

The important advance that has come about by the introduction of Leduc's apparatus is that the amount of degeneration in the neuromuscular apparatus is subject to more accurate mensuration (see p. 478). Heretofore we have had to depend on the crude expression that R. D. is present. By means of the Leduc apparatus an estima-

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[1] Arch. d'Elec. Med., September 15, 1903.

tion of the extent of disease in the neuromuscular mechanism may be secured.

In testing the muscular apparatus, a knowledge of the motor points is desirable if the reaction of the adjacent or subjacent muscles is to be determined. Such points represent the sites at which maximum effects may be obtained with minimum currents. These are usually the points of direct ingress of the motor nerve into the muscle mass. In the case of superficial muscles, particularly in lean individuals, they are sharply delimited; but in fat subjects, and for deeper muscles, diffusion tends to confuse the picture, often very materially. They are illustrated in Plates 1–8.

Fig. 296.—Treatment by galvanic or faradic or rhythmic currents. A smaller active electrode is used in electrodiagnosis.

Modes of Testing.—The horizontal position is generally advisable, with as complete relaxation as possible. In some patients the sitting position is equally convenient. The indifferent electrode, preferably good sized, is thoroughly moistened and placed upon the spine, either at its upper or lower part, depending largely upon the region to be tested. This electrode should be applied firmly to the skin, and held in place either by the weight of the body, the hand, or a bandage. The exploring electrode, provided with make and break mechanism, is then placed over the motor points, and a systematic examination carried out in accordance with the needs of the patient (Fig. 296).

A much more accurate method is that employed by the author, and, so far as he knows, is original with him.

The indifferent electrode is preferably made of block tin $\frac{1}{32}$ inch thick, and 2 by 3 inches in area. For this I have slip-covers made of absorbent felt.

The part of the body on which the indifferent electrode is to be placed should be thoroughly washed, using tincture of green soap. The slip-cover is thoroughly wet in a solution of bicarbonate of soda, consisting of 1 dram of bicarbonate to 4 ounces of water.

The exploring electrode, as shown at B, Fig. 297, consists of a circular disk made of pure block tin, and having a groove around it so that it can be easily covered with a piece of chamois. This chamois is to be thoroughly wet in the bicarbonate of soda solution. The area to be explored should be thoroughly cleaned, using the usual green soap tincture. This is to remove any fatty material which would offer a high resistance.

In place of the usual interrupting handle, Fig. 297, C, I use a combination electrode. B is screwed into the handle, E. Inside of this handle is a compression spring. The central metal rod F has the upper part graduated, so as to indicate the amount of pressure with which the electrode B is held in contact with the skin. As a rule, using an electrode $\frac{1}{2}$ inch in diameter, a pressure of $1\frac{1}{2}$ pounds is sufficient.

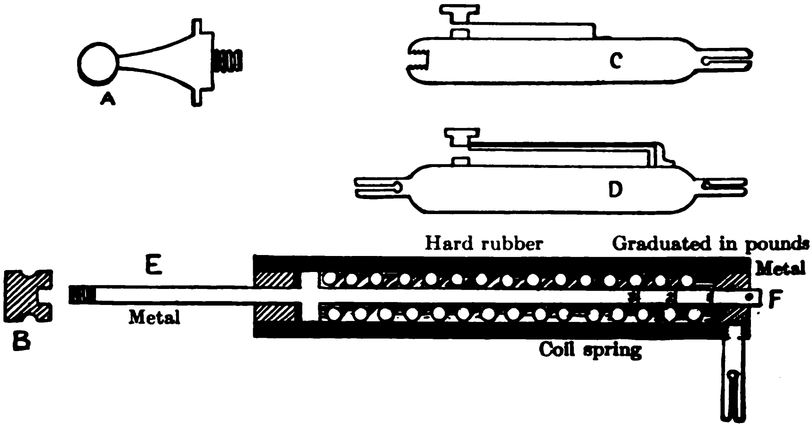

Fig. 297.—Author's exploring electrode with standard pressure.

In circuit with this holder is placed a separate interrupting handle shown by Fig. 297, D. This is held in the left hand of the operator, so that as the exploring electrode is moved from one place to another, the pressure used to make and break the circuit in D will not affect the contact pressure between the electrode and the patient. This is a most important point, as the resistance will vary according to the pressure. This is more particularly so when a sponge electrode is used in place of the chamois-covered metal electrode above described.

Investigators with large experience advise the beginning of an examination by means of the faradic current, In this manner it is held that polarization is prevented. Furthermore, if no alteration in faradic excitability is obtained by minimum currents, it usually follows that there are few changes to the galvanic current. In beginning the testing it is advisable that the exploring electrode be connected with the negative pole of the secondary current. The strength of the current is gradually increased until the beginning of excitation is reached, and the number of millimeters that the secondary covers the primary is noted. A comparison of the two sides of the body is always advisable in carrying out tests with the faradic current, since accurate methods of measurement are not usually available apart from a physiologic laboratory. Stintzing has given tables for the faradic current as follows, the figures referring to his own coil:

FARADIC EXCITABILITY OF NERVES.—(*Stintzing.*)

	Boundaries. *Upper.* (Millimeters between the primary and secondary coils.)	*Lower.*
1. Spinal accessory	145	130
2. Musculocutaneous	145	125
3. Mental	140	125
4. Ulnar I	140	120
5. Ulnar II	130	107
6. Frontal	137	120
7. Zygomatic	135	115
8. Median	135	110
9. Peroneal	127	103
10. Crural	120	103
11. Tibial	120	95
12. Radial	120	90
13. Facial	132	110

In testing with the galvanic current, we follow out the same procedure, first obtaining the minimum reaction, and then ascertaining if the force of muscular contraction follows out the law of progression, CCC>ACC>AOC>COC (cathodal closure contraction is greater than anodal closure contraction, etc.).

The strength of the current necessary to produce a reaction is then read off on the milliamperemeter. Thus a record of a radial nerve may read as follows:

CCC = 2.0 ma.
ACC = 3.0 ma.
AOC = 4.5 ma.
COC = 5.0 ma.

(Minimal cathodal closure contraction occurs with 2 ma., etc.)

We have seen that variations in contraction in diseased conditions may exist as to the quantity, as to the quality, or both. Thus, increase, diminution, or abolition of contraction may result. For example, an increase in contractility is obtained in strychnin-poisoning, in hysteria, in tetany, and other affections to which attention will be called later. Such an increase is determined by comparison with the tables. A decrease in nerve excitability is obtained in many cases of neuritis, in poliomyelitis, etc., while an abolition may be present in the same affections.

Qualitative variations consist in variations in the form of contraction, such as slowness, and variation from the typic galvanic formula.

A complex reaction, both as to slowness and variation from the typic formula, constitutes the well-known *reaction of degeneration.*

Reaction of Degeneration.—This may be recognized as existing in several degrees which have been arbitrarily named slight, medium, and severe.

Anomalies of Faradic Excitability.—These may be discussed before the main subject of the reaction of degeneration syndrome is considered. They consist, in the main, of hyperexcitability and faradic loss, or the phenomenon of exhaustion.

Faradic hyperexcitability is found in conditions in which muscular rigidity is usually accompanied by an increase in tendon excitability, such as is seen in tetany, in tetanus, in many of the occupation neuroses (writer's cramp, telegrapher's cramp, violinist's cramp), in paralytic posthemiplegic states, both of recent and of remote origin, and in those cases in which irregular involvement of the pyramidal tracts (posthemiplegic chorea, posthemiplegic athetosis, posthemiplegic pseudoparalysis agitans) takes place.

Faradic exhaustion is a constant symptom in many myopathics, in many tabetics, in myasthenias, in Thomsen's disease, and in a number of conditions which show reaction of degeneration.

Anomalies of Galvanic Contractibility.—Galvanic hyperexcitability has been spoken of. In addition to the disorders mentioned, it is a frequent accompaniment of conditions in which mechanic hyperexcitability is also present, in multiple sclerosis, in spastic paraplegic states. Galvanic loss is a constant accompaniment of the terminal stages of neuromuscular degeneration.

Galvanic Inversion.—Rich's Formula.—In some instances the physiologic order of CCC>ACC>AOC>COC may be partially inverted to read ACC>CCC>AOC>COC; or when ACC>CCC>COC>AOC occurs, a total inversion has taken place. In some instances the formula described by Rich is present, as follows: CCC>ACC>AOC>COC. These inversions are all varieties of the reaction of degeneration, and their presence is an indication of a degeneration occurring in the lower motor neuron, either in the ganglion-cells of the anterior columns of the cord or of the nerve-fibers passing from these cells to the muscle. It is absent in affections of the primary motor neuron system *per se.* If the researches of Iotyko are correct, the reaction of degeneration may be interpreted as a failure in the striated elements of the muscles to react, with a persistence of sarcoplasmic irritability.

Longitudinal Reaction.—This special application, first referred to by Remak, occurs in those muscles which show the reaction of degeneration. In such muscles the contraction is more readily brought about when the testing electrode is applied at the distal end of the muscle, rather than when the application is made to the motor point, which latter has, as Doumer has termed it, lost its importance. The importance of the longitudinal reaction, which is great, is that it is a more delicate test, and that in old, long-standing cases, in which the nerve paralysis is marked, as in chronic neuritis, old poliomyelitis, etc., contractions may be brought out though they fail when the electrode is applied to the motor point. In certain cases of sluggish reaction the longitudinal reaction test should be employed to settle a doubt as to the presence of reaction of degeneration. Thus, if a stronger and slower contraction takes place with the electrode at the distal end of the muscle than when placed over the motor point, reaction of degeneration is positively shown.

In practical work on electric testing a number of anomalous and contradictory results have been obtained, and it is quite certain that the entire subject of the reaction of degeneration is in need of new restating. At the present time newer results, which have come about by the use of Leduc's new commutator, have not been codified, but they are certainly destined to be of immense practical use. We have already alluded to the fact that more accurate determinations are possible by this form of apparatus, and data are now rapidly accumulating as to the minimal duration of current needed to make visible muscular contractions, and as to the critical frequency at which an interrupted current causes a muscle response.

Development of Reaction of Degeneration.—This syndrome has a more or less regular course of development, both as regards the nerve reaction and the muscle reaction in point of time and in course of events. Both of these are conditioned by the character and the severity of the lesion. Following the complete section of a nerve-trunk, there is usually a short period of increased irritability in the nerve to both faradic and galvanic currents. This may persist for a few days—three or four—and is then followed by the period of diminution, the decline reaching the normal about the fifth or sixth day, and then rapidly sinking below, so that about the tenth day the nervous irritability has completely disappeared.

The course met with *in the muscles* is somewhat modified. Faradic excitability seems to diminish from the very onset, and has disappeared entirely in about a week or ten days, while the reaction to galvanic currents, which has steadily decreased for about a week, then undergoes a more or less abrupt reversal, and an increase in excitability with sluggish contractions takes place, mechanic irritability of the muscle appears, and ACC>CCC appears in many instances. Rich's inverse formula begins to appear, and this may persist for some time —even for weeks. Later, diminution, going on to abolition, takes place.

Sherrington, in his Erasmus Wilson lectures,[1] has gone over this point in his cases of nerve section, and has found that the muscles involved cease to respond to the faradic current in from four to seven days, and that, even with the galvanic current, there may be loss of excitability about the tenth day. The appearance of sluggish muscular contraction on the reversal of polarity takes place about the same time.

In the final stages of degeneration the galvanic excitability diminishes. The AOC first disappears entirely, and is soon followed by the loss of the COC and the CCC, the ACC persisting the longest. The longitudinal reaction may still be pronounced, even after the complete disappearance of the ACC. The longitudinal reaction finally disappears. This has been graphically shown by Guilleminot (p. 318, English translation).

Myotonic Reaction.—This is a special type of electric and mechanic reaction, which was first described by Erb as characteristic of patients suffering from Thomsen's disease, or myotonia congenita. In these patients the excitability of the nerves to faradic and galvanic electricity is practically normal, as is mechanic excitability as well, but there is a

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[1] Lancet, March, 1906.

distinct increase of the muscular excitability to these forms of stimulation. Testing with the galvanic current shows that the muscles react only with the closure contractions, the ACC = CCC. The tonic, slow, and prolonged nature of the contractions is pathognomonic. When stimulated by the faradic current the muscles respond normally to minimal contractions, but on increasing the strength of the current the reaction becomes markedly prolonged, persisting for a number of seconds after complete removal of the current. This period of duration tetanus, as it has been termed, to both interrupted and continuous currents, is very characteristic.

Myasthenic Reaction.—Another type of muscular reaction is observed in the same kind of patients, and in a number of conditions closely allied to the neuromuscular affection known as myasthenia gravis. This reaction consists in the great fatigability of muscle when exposed to the tetanizing action of a persisting faradic current. It differs from the normal physiologic curve by the very rapid onset of the fatigue drop. At the same time the muscular reaction does not depart from the ordinary type on exposure to the single shock of the direct current, notwithstanding the presence of tetanic fatigue.

Neurotonic Reaction.—The exact significance of this reaction is unknown. It consists in the tonic persistence of contraction after cessation of the current, whether it be faradic or galvanic. Further, there is an exaggeration of the anodal response, made evident by the early appearance of AOC and ACC tetanus.

Reactions in Lesions of Spinal Nerve Centers.—Not only does the investigation of the muscle at the site of its motor points offer considerable information concerning the condition of the nerve-supply of the respective muscles, but it not infrequently happens that an entire group of muscles is affected by the loss or reduction of function, and a careful study of a reaction of these groups will lead to a differential diagnosis between the affection of the peripheral distribution as contrasted with a lesion of the motor centers in the spinal cord. Thus it is well known that electric testing of groups of the muscles of the hand will enable one to differentiate between a lesion of the trunk of the median nerve and a lesion of the first dorsal segment in the spinal cord. As has been well pointed out by many authors, in the latter case the whole of the thenar and hypothenar eminences will be involved, as well as all the interossei and lumbricales, whereas if the lesion is confined to the trunk of the median nerve, then the hypothenar, the interossei, the two inner lumbricales, the abductor pollicis, and the inner half of the short flexor will escape, since all these receive fibers from the ulnar nerve. It, therefore, becomes a matter of considerable importance in the differential diagnosis of peripheral lesions due to neuritic process, from central lesions due to myelitic process, to bear in mind the segmental distribution of the motor centers in the spinal cord. While most of these facts are commonplaces for the neurologist, and have been very carefully investigated by followers of this branch of medicine, it is essential, in the electric study of the diseased motor apparatus, that the main facts of spinal cord segments be borne in mind.

The following table, taken from Starr, shows the muscles represented in the group of cells in the various segments of the spinal cord:

II., III. Cervical.	IV. Cervical.	V. Cervical.	VI. Cervical.	VII. Cervical.	VIII. Cervical.	Dorsal.
Diaphragm.	Diaphragm.					
Sternomastoid.	Lev. ang. scap.					
Trapezius.	Rhomboid.	Rhomboid.				
Scalenus.	Supra- and infraspin.	Supra- and infraspin.				
	Deltoid.	Deltoid.				
	Supin. long.	Supin. long.				
	Biceps.	Biceps.	Biceps.			
		Supin. brev.				
		Serratus mag.	Serratus mag.			Second to twelfth dorsal.
		Pect. (clav.).	Pect. (clav.).			
		Teres minor.	Pronators.	Pronators.		Muscles of back and abdomen.
			Triceps.	Triceps.		
			Brach. ant.	Brach. ant.		
			Long extensors of wrist.	Long flexors of wrist and fingers.	Long flexors of wrist and fingers.	First dorsal.
					Extensor of thumb.	Extensor of thumb.
						Intrinsic muscles of hands.

I. Lumbar.	II. Lumbar.	III. Lumbar.	IV. Lumbar.	V. Lumbar.
Quadr. lumb.				
Obliqui.				
Transversalis.				
Psoas.	Psoas.			
Iliacus.	Iliacus.			
	Sartorius.			
	Quad. ext. cruris.	Quad. ext. cruris.		
		Obturator.	Obturator.	
		Adductors.	Abductors.	
			Glutei.	Glutei.
				Biceps femoris.
				Semitend.
				Popliteus.

I. Sacral.	II. Sacral.	III. Sacral.	IV. and V. Sacral.
Biceps femor.			
Semimemb.			
Ext. long. dig.			
Gastroc.	Gastroc.		
Tibialis post.	Tibialis post.		
	Peronei.	Peronei.	
	Intrinsic muscles of foot.	Intrinsic muscles of foot.	
			Sphincter ani et vesicæ.
			Perineal muscles.

Reaction of Sensory Nerves.—Just as the reaction of the neuromuscular apparatus to electric stimulation is evidenced by muscular contraction, so the reaction of the sensory neurons is made known by sensations. In practical work, since mixed nerves are usually involved, the two sets of phenomena are constantly present. As is the case with muscular phenomena, so with the sensory symptoms, certain variations in health and disease are known. These sensations are thought to be largely dependent upon chemic changes, and hence they are usually more apparent at the more definitely chemic terminal of the electric apparatus—the cathode. They vary according to the character of the electrode used, being more distinct with the smaller electrode, by reason of the condensation of current, also with the nature of the electric force employed. Thus the sensation accompanying the use of the mild galvanic current is usually described as that of burning, while that of creeping or prickling more nearly describes the normal sensations induced by the mild faradic current. A further variation exists if different solutions for contact are applied, due to the dissociation of different ions.[1]

Thus, if ordinary salt solution be employed, the sensations are more active at the anode, since the dissociated sodium ions enter at that pole; while if sodium carbonate be used, the CO_2 ions entering at the cathode cause a greater amount of sensation at that pole. The contact, whether complete or partial, also alters the sensation somewhat, perfect contacts being usually much less painful than imperfect ones. Alterations in the rapidity of interruption make a great difference in the sensations produced on the skin. Single shocks are often extremely painful, even apart from the muscular effects produced. When the interruptions commence to be more rapid than fifty to the second, the sensations cease to be individualized, fusion takes place, and with still more rapid interruptions a pleasant, smooth glow may be alone experienced, or with more rapid interruptions numbness or anesthesia may be produced. Leduc's currents for local anesthesia are particularly pleasant in application.

Protopathic and Epicritic Sensibility.—An extremely important, if not epoch-making, research of Head[2] has opened up an entirely new and wide field for investigation with reference to the electric excitability of the sensory nerves, and has enriched clinical neurology with a new classification of sensory nerves heretofore unrecognized. Thus he has described two sets which he has termed the epicritic and the protopathic sensory systems. These show marked differences in their response to electric stimulation, and our present accounts of sensory nerve physiology with reference to electric stimulation will receive an entirely new series of interpretations.

Head's views concerning these two sets of sensory nerves may be briefly summarized as follows: Ordinary sensations of touch are not simple and primary, but consist of at least two forms of sensibility, which have been termed by him protopathic and epicritic, and which sensations are dependent upon two distinct systems of fibers. He was led to this differentiation by a large series of studies on peripheral nerve injuries, and subjected his findings to an exceedingly critical control by operating upon a cutaneous nerve of his own arm. The processes of degeneration and regeneration were carefully studied, and the modifications in sensibility and electric reaction made the basis of an elaborate monograph. As *protopathic sensibility* he describes that form of sensibility which can produce changes in consciousness, but which is incapable of causing a quantitative change apart from the area studied. The position of a point stimulated can be appreciated, and each stimulus causes a widespread radiating sensation, not infrequently referred to parts at a distance. The return of protopathic sensibility to a part, after its loss, brings a cessation of all those destructive changes in nutrition that occur in parts where the skin is insensitive. Ulcers cease to form, and sores heal as readily as on the healthy skin, although the parts remain insensitive to all higher forms of stimulation, such as light touch.

After an affected part has remained for a variable period in this condition, it begins to become sensitive to light touch, and degrees of

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[1] See Sanchez, La theorie des ions en electricite medicale, Nantes, 1902; Leduc, Ionization Medicales, Monographies Medicales, 1907.

[2] Brain, 1905. See also his previous and subsequent papers.

temperature which produce the sensations called warm and cool on the normal skin are again distinguished correctly one from another. With the gradual return of sensation it again becomes possible to discriminate two points touching the skin at distances more nearly normal, and the widespread radiation, so characteristic of the first stage of recovery after the severance of a peripheral sensory nerve, ceases, and is replaced by an increasing accuracy of localization. It is for this form of sensation that Head has proposed the term *epicritic*.

Head comes to the general conclusion that the sensory mechanism consists of three systems: (I) Deep sensibility, capable of answering to pressure and to the movements of parts, and even capable of producing pain under the influence of excessive pressure, or when a joint is injured. The fibers subserving this form of sensation run mainly with the motor nerves, and are not destroyed by division of all the sensory nerves of the skin.

(II) Protopathic sensibility, capable of responding to painful cutaneous stimuli and to the extremes of heat and cold. This is the great reflex system, producing a rapid, widely diffused response, unaccompanied by any definite appreciation of the locality of the spot stimulated.

(III) Epicritic sensibility—by which we gain the power of cutaneous localization, of the discrimination of two points, and of the finer grades of temperature called cool and warm.

With reference to their distribution, the entire body, without and within, is supplied by the protopathic system. The fibers of this system in the skin may be spoken of as somatic, those of the internal organs as visceral, protopathic fibers. Thus one should speak no longer of the afferent sympathetic system, but of the protopathic supply of the internal organs.

Another set of fibers peculiarly associated with impulses of movement and of pressure exist in connection with the Paccinian organs. In the body and limbs an analogous system is found, peculiarly liable to pressure, to the localization of movement, and to the appreciation of position. The fibers in this system run in conjunction with the motor nerves.

In addition to these two systems, which are distributed to all parts of the body within and without, the surface of the body only is supplied by a third—the epicritic system. This endows the skin with sensibility to light touch. To the impulses conducted by this system is due the power of localizing the position of cutaneous stimuli, of discerning the doubleness of two points, and of discriminating between minor degrees of heat and cold, and other special attributes of sensation. The fibers of this system are more easily injured, and regenerate more slowly than those of the protopathic system. They are evidently more highly developed, and approach more nearly to the motor fibers which supply voluntary muscles in the time required for their regeneration.

There is a distinct difference in these two systems to electric stimulation, especially to interrupted currents. Protopathic sensibility does not seem to be affected by such currents whose duration is less than 0.002 of a second, and consequently current waves having that duration or less produce a stimulation which is more or less devoid of painful impressions as the duration of the impulse decreases, though they are still felt quite distinctly as a sensation through the agency of the epicritic fibers.

Sensory Nerve Reactions.—These may be determined for the galvanic current by means of a wire brush attached to the cathode. The anode, usually a wet sponge, being placed in the hand or on the sternum. The quantity of current which is regulated by a rheostat in series or by a shunt gives the figures for minimal pain reaction. The varying degrees of skin resistance render this method irregular as to results.

Testing by the faradic current is done by the examining electrode, and the strength determined by the movement of the secondary coil on the primary. The amount of separation of the coils affords a measure of the strength of the current necessary to produce minimal sensations.

Erb's table of normal faradic excitability is given as follows:

PLACE OF EXAMINATION.	FIRST SENSATION—SEPARATION OF COILS.	MARKED PAIN—SEPARATION OF COILS.
Cheek	200–220 mm.	120 mm.
Neck	180–220 "	120 "
Arm	200 mm.	120 "
Forearm	190 "	115 "
Dorsum of hand	175 "	110 "
Tip of finger	125 "	90 "
Abdomen	190 "	120 "
Leg	170 "	110 "
Dorsum of foot	175 "	110 "
Sole of foot	110 "	80 "

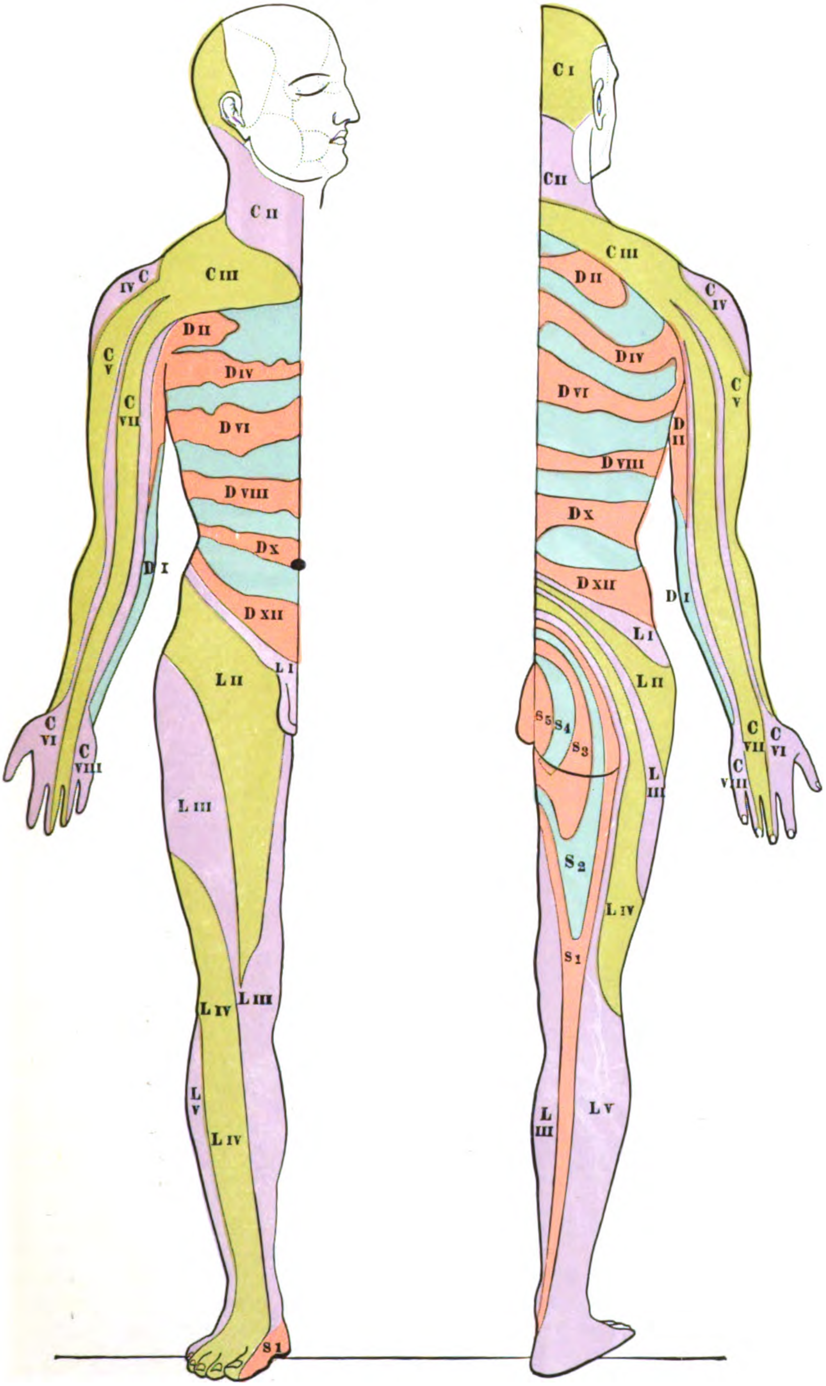
Modifications in the Effect of Faradic Currents.—Muscular contraction is chiefly produced by the use of a faradic coil with coarse wire or one with a small length of secondary wire, perhaps 1500 feet. It is not produced at all, or not to the same extent, if a coil with fine wire or one with a great length of secondary wire, say 8000 feet, is used. Slow vibrations favor muscular contraction and the most rapid interruptions aid in preventing it. Faradic currents from a coil with fine wire and extremely rapid interruptions have an effect upon the nerve which is very beneficial in neuralgia and neuritis.

A faradic current of a quality to produce muscular contraction may have its strength regulated by motion of the secondary coil upon a sort of sledge. When the secondary coil is very far from the primary coil the current may be so weak as not to cause contraction.

Sensory perception follows a law comparable to the law of muscular irritability so far as the epicritic sensations are concerned. To galvanic currents the first sensation is noted, according to Bordier's researches, as follows: CClS, AnCS, AnOS, COS.

Segmental Distribution of Sensory Nerves.—The researches of Starr, Kocher, Thoburn, and, more recently, of Head and Sherrington have served to bring out a series of facts concerning the relationship of the segmental distribution of the sensory nervous system. Each segment of the spinal cord has a more or less regular segmental representation in the periphery. Electric testing for distribution of sensation has not advanced, so far as practical clinical purposes are concerned, to the same degree as motor tests, but a careful study of these segmental areas in the skin affords a very important means of diagnosis of both peripheral and central lesions. The spinal segmental distribution of the sensory nerve areas do not at all coincide with the peripheral distribution of the sensory nerves. (See Figs. 298, 299, 300, and Plate 9.)

PLATE 9



Areas of anesthesia upon the body after lesions in the various segments of the spinal cord. The segments of the cord are numbered: C i to viii, D i to xii, L i to v, S 1 to 5, and these numbers are placed on the region of the skin supplied by the sensory nerves of the corresponding segment (Starr).

Nerves of Special Sense.—The reaction of nerves of special sense is individual and specific. Electric stimulation of the *olfactory nerve* is of little known practical value. The sensation of the smell of phosphorus is often given as an approximate description of this reaction sensation.

Optical stimulation results in a sensation of a flash of light. According to the direction of the current, certain differences have been observed, but marked individual variation undoubtedly exists. Cathodal closure is thought to give a reddish flash, and anodal closure a bluish tinge. Bremer has constructed special formulas for the reactions of optic-nerve stimulation. CC and AO over the closed eye, he states, cause perception of a light central disk, surrounded by a narrow fainter zone. CO and AC cause a weaker perception in an inverse order. Electric stimulation of the eye with strong currents is not without its special dangers, blindness, presumably from retinal hemorrhage, having been reported by a number of observers from Duchenne's time to the

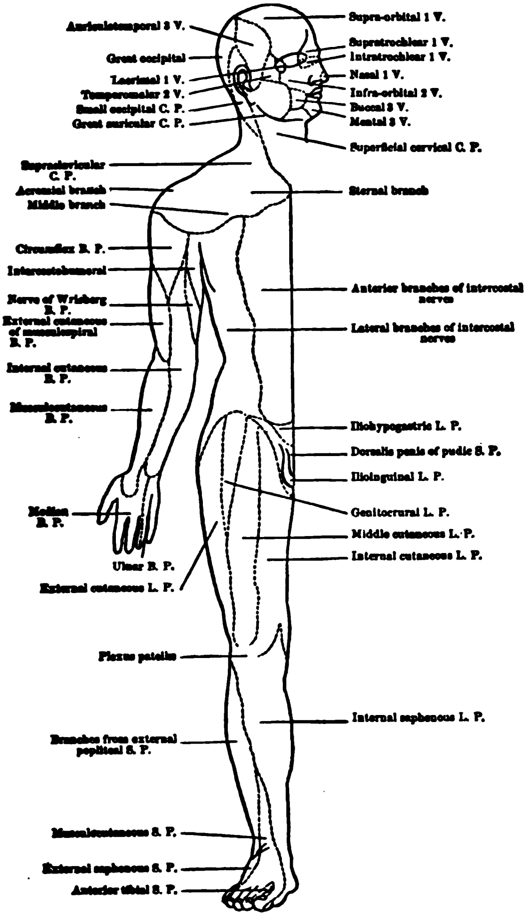


Fig. 298.—Cutaneous distribution of nerves (after Flower).

present. From a diagnostic standpoint optical electric testing has given few definite results.

Auditory stimulation requires strong currents and results in perception of sounds, as of whistling, blowing or buzzing, being most pronounced to CC, less so to AO; ACl and CO give no results in health. Many individuals give no reactions whatever. In pathologic states, particularly in perforation, the reaction is usually more pronounced, constituting a distinct hyperesthesia of the auditory nerve. In some instances of hyperesthesia ACl and CO, which normally give no response, may do so.

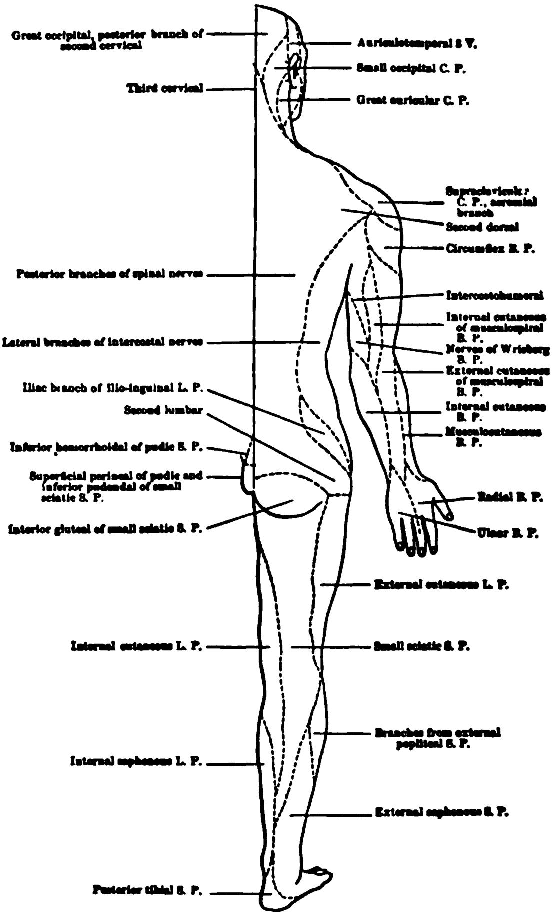


Fig. 299.—Cutaneous distribution of nerves (after Flower).

Loss of auditory excitability may be encountered, and an inversion of the formula has been noted in rare cases of inexact significance, and what is known as a paradoxic reaction is known in which the opposite ear reacts, while that to which the electrode is applied does not respond, or only feebly. Voltaic vertigo is described on page 387.

Gustatory perception may be aroused by electric stimulation, both when the tongue is stimulated and when the electrodes are applied to the back of the neck. One of the author's patients always noted a metallic taste when electrodes were applied to the forehead and epigastrium.

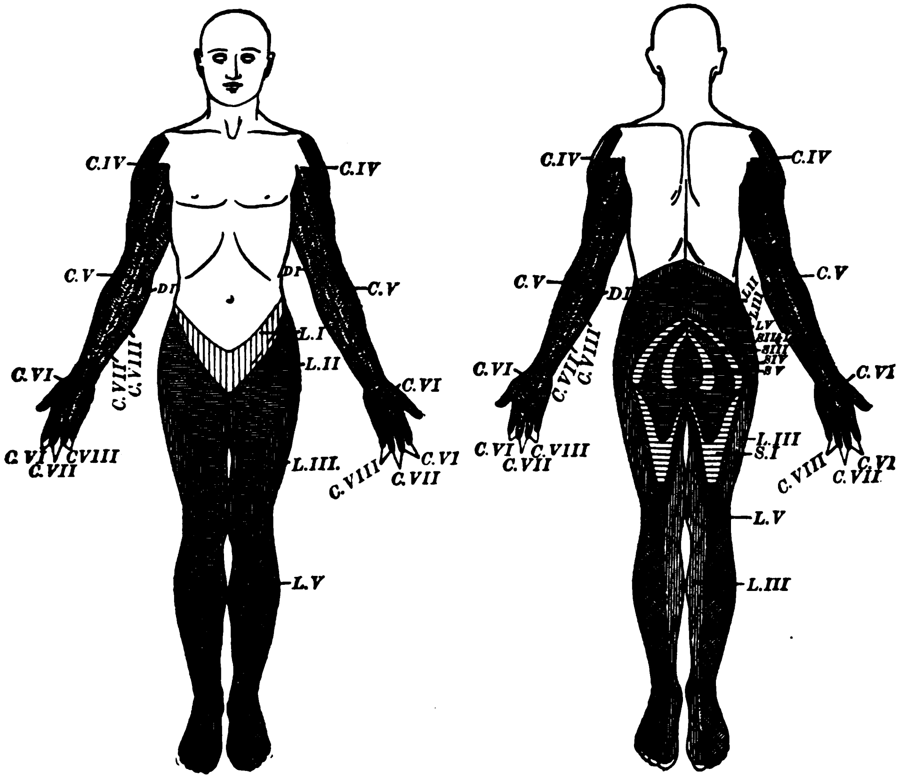


Fig. 300.—Cutaneous areas related to the spinal-cord segments (Starr).

Stimulation by the anode causes an acid metallic taste; by the cathode, an alkaline bitter taste. Such gustatory sensations may be aroused by minimal currents and may be subject to loss.

DISEASE OF THE PERIPHERAL SENSORY NERVES

Anesthesia is best treated by a faradic brush electrode.

DIAGNOSIS AND TREATMENT OF DISEASES OF PERIPHERAL MOTOR NERVES AND MOTOR CENTERS

For purposes of convenience central and peripheral lesions will be discussed together in the following pages.

Palsies of Cranial Nerves

The important motor cranial nerves affected peripherally are the facial, hypoglossal, and spinal accessory. The ocular muscles are more often involved centrally, although following many toxemias the peripheral distributions of the third, fourth, or sixth may be affected.

Ocular Muscles.—There are many difficulties surrounding the investigation of the eye muscles. The sensitiveness of the conjunctiva and cornea, the delicacy of the retina, and the deep seat of the eyeball itself all make the study of the ocular palsies difficult and exasperating. The intricacy of the innervation plays an important part as well. It is convenient to consider the third, fourth, and sixth nerves together, since they are so closely allied in their functions. The third nerve has the widest distribution, supplying all the external muscles of the eye save the superior oblique, which is supplied by the fourth, and the external rectus, which is supplied by the sixth nerve. The voluntary part of the levator palpebræ superior is also supplied by the third; the involuntary part, by the cervical sympathetic nerves. The third nerve also goes to the interior of the eye, supplying, through the ciliary ganglion, the ciliary muscle and the sphincter pupillæ. The ciliary ganglion is at present considered by a number of scholars to be the peripheral motor nucleus for the sphincter pupillæ.

Complete paralysis of the third nerve gives ptosis, external strabismus, inability of the globe to move upward, straight down, or decidedly inward. The pupil is dilated and does not contract on exposure to light. Complete paralysis is rare. Hysteric paralysis is not unusual, but so far as the ptosis is concerned, is usually differentiated from organic paralysis by the absence of an overacting levator of the other side.

Electric tests are unavailing in determining the peripheral or central character of a third-nerve paralysis, although the longitudinal reaction has been obtained in levator palpebræ paralysis.

In nuclear lesions it is important to bear in mind that the orbicularis oculi is also involved. Transient ocular palsies, such as occur in ophthalmic migraine, should not be confounded with true ocular palsies.

Fourth-nerve paralysis causes a characteristic diplopia, which is not capable of electric analysis.

Sixth-nerve paralysis—paralysis of the external rectus—causes a characteristic and isolated internal squint.

Therapy.—These ocular palsies may be treated by electric stimulation, but it cannot be said that the treatment is always satisfactory. Only after thorough antisyphilitic and antirheumatic treatments have been persistently carried out is one warranted in trying electricity. Even in hysteric ptosis one is not warranted in abusing the electric treatment for fear of excess of suggestion. Electric stimulation of the levator palpebræ is at times useful. Such electric stimulation as recommended by Everthain and Salomonson should be done by a button electrode applied about ⅛ inch under the highest part of the supra-orbital arch.

The method followed for treatment of the ocular palsies by electricity is by direct application of the cathode to the eyelid, the anode being placed at the nape of the neck. The finger may be used as a cathode, or small fine sponges may be employed.

Rhythmic faradization with one electrode applied to the eyelid at the insertion of the tendon of the paralyzed muscle and the other electrode at the nape of the neck gives successful results.[1]

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[1] Chabry, Bulletin officiel de la Societe Française d'electrotherapie, p. 135, 1905.

Facial Nerve.—This nerve is more frequently subject to disease than any other cranial nerve.

The lesion itself may be treated by bilateral stimulation with galvanic currents. An electrode about 2 cm. (⅘ inch) in diameter is placed in each auriculomastoid fossa, the negative electrode being on the affected side. A current of 6 or 8 ma. is allowed to flow for five minutes.

Electricity may be used to maintain the nutrition of the paralyzed facial muscles and hasten the return of power.

In cases in which faradic excitability is present the paralyzed muscles may be exercised by faradic currents and a trophic effect upon them may be secured by galvanic currents. One of the best applications is the de Watteville, or galvanofaradic current, rhythmically varied in intensity and direction by the rhythmic rheostat and pole-changer or some similar apparatus. The galvanic current has a maximum intensity of 5 or 6 ma. and the faradic coil has coarse wire and slow interruptions and a strength of current sufficient to cause contraction of the facial muscles. One electrode is held in the hand, and the other is applied for about a minute to the motor point of each of the paralyzed muscles. In the absence of special apparatus the galvanic and faradic currents may be applied separately. Stimulation by isolated induction shocks or by condenser discharges are more valuable in treating the muscles of the face than those elsewhere. These muscles are short, and do not have the inertia of a considerable weight to overcome. The abrupt contraction produced by the applications is not, therefore, so undesirable as it is elsewhere.

Isolated induction shocks cause contractions which are much more sudden in onset and subsidence and much briefer in duration than physiologic contractions. They are not generally desirable in electromechanotherapy, but perhaps are all right for exercising the small muscles of the face which normally do not have much resistance to be overcome by their contraction.

Paralysis of the entire innervation of the seventh nerve is not common, save in central lesions; paralyses of separate branches are very frequent. It is a highly complex nerve, and is probably not a pure motor nerve, but has a sensory root as well, probably, as Hunt[1] has shown, in the geniculate ganglion. The typic involvements of the facial nerve take place—(1) Outside of the stylomastoid foramen, leading to Bell's paralysis; (2) within the Fallopian canal; (3) between its emergence from the pons and the geniculate ganglion, and (4) within the pons.

(1) In *Bell's palsy*, due to refrigeration, to injuries, or to tumors, there is complete palsy of the muscles of the corresponding side of the face to both voluntary and emotional impulses. On looking down, if an attempt is made to shut the eye, there is even a slight raising of the eyelid on the paralyzed side, owing to the unopposed levator palpebræ. The face is flattened out and loses all its wrinkles, the conjunctiva becomes reddened, and the eye brims with tears. The eyelids can be closed practically only during sleep, when the levator is relaxed. The food cannot be forced out of the paralyzed side of the cheek behind the teeth, and the vasolabial folds are obliterated.

Electric testing is advantageous in determining the extent of the

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[1] Hunt, J. R., Herpetic Inflammation of Geniculate Ganglion, Journal of Nervous and Mental Diseases, February, 1907.

paralysis. The trunk of the facial may be tested in two positions—(*a*) In the angle between the descending ramus and the mastoid process. Here stimulation produces a contraction of all the muscles supplied by the facial, although contractions of the muscles of the upper branches—frontal and corrugator supercilii—are less powerful than the others. This is a normal phenomenon, and should not lead to a misinterpretation as to the contractibility of these muscles.

(*b*) A second point is at the tragus of the ear. Here only the second and third branches are stimulated, and at times the reaction is wanting entirely.

The *three branches of the facial* may each be tested separately. The stimulation of the upper branch causes wrinkling of the forehead and eyebrow: that of the middle branch, at a point just beneath, over the tuber ossis zygomatici, causes closing of the eye, smiling movement, turning up of the angle of nose, and a pout-like wrinkling of the upper lip; stimulation of the lower branch causes turning over of the under lid, lifting of the chin, and drawing of the mouth downward and outward. In making these tests it is desirable to bear in mind that of the three branches, the upper branch is the most excitable, the middle branch the least, and, further, that tests with the faradic current are apt to be painful, and that with the galvanic current dizziness, light flashes, etc., are usual unpleasant by-effects. Minimal currents should be employed in all tests of the facial innervation.

Reaction of degeneration is often found very early, and is usually very complete. In mild cases reaction of degeneration may be absent. Reaction of degeneration comes on slowly; reaction to the induction-coil current may persist for a week or ten days, and no prognostic data are obtainable within that period. Reaction of degeneration of irregular distribution, *i. e.*, involving one or two branches only, is of better prognostic import, as a rule, than when the three branches are involved.

Electric treatment is highly beneficial in most cases of Bell's palsy, electrically treated cases nearly always recovering more rapidly than untreated cases. Persisting reaction of degeneration should lead one to investigate thoroughly as to the cause, especially if it has been hastily inferred that the paralysis is due to refrigeration.

The cases due to refrigeration (cold) have a good prognosis in the main. The treatment should be carried out daily, direct applications being made to both the nerve-trunk and to the muscles. Both faradic and galvanic currents are advisable in those cases with definite reaction of degeneration. It is desirable to place the positive electrode on the nape of the neck, and the negative electrode should traverse the innervation of the affected branches from the center to the periphery. Treatment of the skin and muscles by the induction-coil is also advisable. The latter alone is needed if reaction of degeneration has not set in.

Séances should not last over five minutes on the average. Mild cases usually recover in from two to three weeks—two to eight months is not too long for a severe case to persist and recover.

In long-standing intractable cases anastomosis is useful, either through the hypoglossal or the spinal accessory. Following such anastomosis further electric stimulation is advantageous.

(2) In *lesions of the facial within the aqueduct*, one may find additional symptoms due to involvement of other structures, notably the geniculate ganglion and the chorda tympani nerve. Thus various

irregular herpetic eruptions, associated with involvement of taste in the anterior two-thirds of the tongue of the affected side, and irregular acoustic symptoms may be found. If the symptoms of herpes, facial palsy, loss of taste, and acoustic symptoms are present, there is undoubtedly true inflammation of the geniculate ganglion, with direct extension of the inflammation to the sheath and connective tissues of the nerve. In the mild palsies inflammatory edema and pressure are responsible, while in the severe types inflammation brings about structural alterations. J. R. Hunt[1] was the first to show the generic relation of the facial palsies with an herpetic inflammation of the geniculate ganglion. He has described a number of types which are purely of neurologic interest.

Many of these cases run precisely the same course as the more distinctly peripheral ones. Save for the richer symptomatology, they vary but little from the preceding group.

It is advisable, in treating these cases, to wait until all symptoms of geniculate ganglion inflammation have subsided, and electric treatment is best deferred for from two to three weeks.

(3) In *facial palsies without taste involvement, but with loss of hearing*, the nerve is involved between the geniculate ganglion and the pons. These cases are not infrequent in cases of fracture of the skull, in basal disease, and as a result of the herpetic inflammation of the geniculate.

They are to be treated in much the same manner as the preceding group.

(4) When the *lesion is within the pons*, there is no involvement of taste or hearing, but an involvement of the sixth nerve is usually present by reason of the anatomic contiguity of the nucleus of that nerve.

Electricity is of service in these cases as well, but does not, as a rule, give as hopeful results. These nuclear lesions are usually syphilitic or metasyphilitic, in the latter case often appearing very early in tabes and in general paresis. In these latter affections, naturally, electric treatment of the facial nerve is useless.

Bilateral Facial Palsy.—This is a rare affection, being due most often to syphilitic basilar meningitis, or to alcohol, diphtheria, or double otitis media. Double geniculate affections have not yet been described, but are possible. In certain myopathies a pseudo-double facial palsy is encountered.

In facial palsy of alcoholic, diphtheric, or otitic origin, the general procedures advocated for unilateral palsy are applicable.

Vagus Nerve.—Paralysis of the soft palate and the larynx result from lesions of the vagus. In paralysis of the soft palate the reaction of degeneration is sometimes encountered, especially in diphtheric neuritis. In such a condition electric treatment is of certain avail, particularly in shortening the period of regurgitation of food through the nose.

In paralysis of the vocal cords from recurrent laryngeal involvement electric stimulation is beneficial.

Adductor palsy is bilateral; the patient suddenly loses the voice, yet can talk in a whisper; there is no stridor, and laryngoscopic examination shows the cords to move outward normally.

Strong faradic shocks often make an immediate cure of hysteric aphonia. (See Hysteria.)

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[1] Journal of Nervous and Mental Disease, vol. xxxiv, p. 73, February, 1907.

In laryngeal paralysis due to tabes electric therapy is practically unavailing, nor is it palliative even in laryngeal crises.

Spinal Accessory Nerve.—Involvement of this nerve produces changes in the sternomastoid and trapezius, causing the head to be held toward the opposite shoulder, with downward and outward displacement of the scapula. The scapular displacement is modified greatly if an attendant lesion of the cervical roots be present. Surgical lesions are mostly responsible for involvement of this nerve.

Treatment is to be carried out according to the procedures already outlined for paralysis of the facial nerve.

Hypoglossal Nerve.—Paralysis of the hypoglossal results in hemilingual atrophy. This is a comparatively rare disorder. It may be of central or peripheral origin, in the former case depending on syphilis, tabes, or paresis. Tumors, stab wounds, basilar meningitis. trauma with marked sudden rotation of the neck, may all bring on peripheral palsy.

There are no particular features attending the electric treatment of hypoglossal palsy. It is rarely isolated, as syphilis is the most frequent cause, in which case it is accompanied by associated palsies of the contiguous nuclei.

The peripheral cases frequently recover without any treatment, although electric stimulation hastens such a result.

Bulbar Palsies

As a result of acute or subacute poliomyelitis, several of the medullary nuclei may be involved. This is particularly true in what is known as glossolabial paralysis, which is a mixed paralysis, involving, for the most part, portions of the nuclei of the seventh and twelfth nerves. The electric phenomena observed in examinations in this disorder. whether in the acute or the chronic stages, are usually of a mixed character. There are healthy fibers interspersed with unhealthy fibers, the result being that an indefinite reaction of degeneration is obtained, some of the fibers retaining the normal reaction, while adjacent fibers present typic reaction of degeneration. These mixed reactions are found in practically all the atrophies, especially of the central type; that is, when the motor cells in the medulla or spinal cord are involved. They are less often present in the paralyses of a peripheral type, and, therefore, are of a certain amount of diagnostic significance.

The electric treatment of bulbar palsy offers a considerable field of operation. The best results are usually obtained in the distribution of the seventh nerve, although it is not impossible to obtain some beneficial results in other nerve regions.

It should be borne in mind that bulbar palsy may be found in a number of conditions. It may be hysteric or infantile, or it may be due to unknown and unappreciated pathologic conditions, but its most frequent occurrence is, as has already been stated, in poliomyelitis, in chronic progressive muscular atrophy, and as a complication of amyotrophic lateral sclerosis.

Attention has already been called to the differentiation of true bulbar palsy from so-called pseudobulbar palsy, or myasthenia gravis. Here the myasthenic reaction is usually sufficient to mark it.

It should be borne in mind that electric treatment of bulbar palsy is not without very distinct danger. The ordinary faradic or galvanic irritation, such as is practised in the treatment of ordinary paralyses, has at times led to disastrous results, and even to death. Oppenheim has called particular attention to this danger. Central galvanization, however, is of value.

The exact indications for the electric treatment of bulbar palsy are not yet defined suitably, and up to the present time we have no really reliable information bearing on the therapeutic usage of other forms of electric energy in this affection.

Paralyses in the Cervical Region

As is well known, the spinal muscular types of paralysis have a picture which is characteristic. If the motor neuron is involved at its center, namely, in the ganglion-cell within the anterior horns of the spinal cord, the muscles involved are usually affected from the outset. They acquire the full and maximum amount of paralysis very rapidly, and recovery is gradual and slow. In the peripheral paralyses, *i. e.*, when the motor neuron is affected through its distal distribution—apart from severance or acute pressure—the onset of paralysis is usually slow and gradual, and atrophy becomes apparent only after some time. In both types the limb, if the whole member is involved, hangs helpless—never stiff. The joints are relaxed and the articular surfaces are usually separated by the weight of the member. The muscles are flabby and relaxed and show little or no myotatic irritability. The tendon reflexes are partially or wholly gone. Their persistence in the face of a flaccid paralysis usually means the implication of the adjacent pyramidal tracts.

Such forms of paralysis are common in poliomyelitis, acute and chronic, in amyotrophic lateral sclerosis, in tumors and hemorrhages within the cord, in embolism or thrombosis leading to softening, in the early stages of myelitis, in syringomyelia, and in the various forms of neuritis, whether due to lead, alcohol, mercury, arsenic, diabetes, etc. The muscle arrangements in the cells of the cord have already been referred to, and the localization of the cell groups in the various segments given in tabular form. (See p. 449).

Functional or Organic Paralyses.—It remains first, in making a diagnosis in paralysis, either of the upper cervical type or of the lower lumbar type, or when hemiplegia or paraplegia is present, to determine whether the paralysis is organic or functional. The differentiation between these is in most cases comparatively simple, yet in a large number of others it is by no means an easy matter. This is particularly true, for instance, in the early palsies of disseminated sclerosis, where the tremor and the weakness very frequently simulate a like condition in hysteria. As a rule, muscular atrophy is not an accompaniment of functional disease, at least not in the early stages, and the electric reaction of degeneration never occurs in functional disorders unless muscular atrophy is found as a result of many years of disuse of a muscle group. In some of these cases a reaction of degeneration sufficient to raise a query may be found. As a rule, the functional paralyses involve whole groups of muscles, or even whole muscle functions. Involvement of single muscles is usually diagnostic of organic disturbance.

The *differentiation* of organic paralysis in the lower neuron type, that is, in the spinal muscular neuron, is a comparatively easy affair, since the features already outlined are usually sufficient to develop a definite diagnosis, but in the corticospinal neuron types, where no atrophy is to be expected, and where the reaction of degeneration does not take place, differentiation becomes ofttimes fraught with difficulty. There are cases of hysteric hemiplegia and hysteric paraplegia which defy the ordinary positive tests of electric or neurologic examination.

In the hysteric hemiplegias and paraplegias, the study of some of the more complicated tendon reflexes offers a clue to diagnosis. The reflexes most often studied and upon which most reliance may be placed are those of Babinski and Oppenheim. The *Babinski reflex* is almost invariably present in the organic hemiplegias and paraplegias. The *Oppenheim reflex* has much the same significance as the Babinski reflex.

Grasset's sign, which is less well known, consists in the inability of an organic hemiplegic while lying flat upon the back to lift both the limbs from a table or bed, but being able to lift each one separately. The reason for this is that the organic hemiplegic, by reason of defects about the pelvis, is unable to fix the bones about the pelvic girdle, and is thus unable to lift both legs at one time. The legs should be separated so that the one cannot mutually help the other. The hysteric has no difficulty in raising both legs—*i. e.*, of course, speaking of the milder types of the disease in both instances.

Certain of the more prominent paralyses of the cervical region will be here considered. The most important of these are the paralyses of the trapezius, sternomastoid, serratus magnus, scapular muscles, and deltoid. Certain combined paralyses of the shoulder-girdle, such as Erb's palsy, are of great importance.

Sternomastoid and Trapezius.—These muscles are usually involved more or less in unison, their cell groups lying close to one another in the cord. When both are involved, a central lesion is predicated, although operations about the neck sometimes result in injury to their peripheral nerve-supply. The bringing of tension on the sternomastoid by forced rotation of the head is usually sufficient to demonstrate a change in this muscle.

Paralysis of the trapezius results in a marked drooping of the shoulder, since this muscle is of so much importance in supporting it. The scapula is tilted with its upper end away from the median line and depressed, the lower end approaching the vertebral column and elevated somewhat. On raising the arms above the head the outer end of the clavicle becomes visible from behind.

Electric treatment by means of both galvanic and faradic shocks should be energetic and prolonged. In surgical cases associated with complete reaction of degeneration in all the fibers of the muscle after ten days or two weeks, prompt surgical splicing should be instituted. Even after months or years the results of surgical severance may be obviated by surgical intervention combined with electric treatment.

Serratus Magnus.—Paralysis of this as an isolated muscle is rare, though by reason of the fact that its nerve-supply runs in the substance of the scalenus medius muscle it may be subjected to traumas, particularly in neck operations. The deformity is characteristic.

Extension of the arms forward at right angles to the axis of the body causes a marked wing scapula, the posterior edge appearing as a ridge. With an attendant deltoid paralysis the inability to extend the arms forward makes it impossible to bring out the phenomenon.

In testing for this paralysis Jones recommends that the indifferent electrode be placed in the posterior triangle of the neck and the active electrode applied to the serrations of the muscle.

In paralysis of this nerve as a result of infection or pressure (as seen in some special occupations—poling boats etc.), electric treatment is very effective.

Supraspinatus and Infraspinatus.—In paralyses of these muscles external rotation of the humerus becomes an awkward affair; writing becomes difficult, and the ordinary sewing movements of pushing a needle in and taking it out of a fabric are impossible. Atrophy of the muscles causes a ridge of the scapula to stand out prominently. As the supraspinatus lies deep beneath the trapezius, electric reactions are difficult to obtain. In obstetric paralysis the suprascapular nerve, which supplies the spinati, may be involved in conjunction with the circumflex.

Electric treatment for these paralyses differs in no essential particulars from that in other parts of the body.

Deltoid Paralysis.—The circumflex, derived from the fifth, sixth, seventh, and eighth cervical nerves, supplies the deltoid and the teres minor. Inability to raise the arm is the chief sign in deltoid paralysis. The muscle wastes and the shoulder flattens. The acromion process becomes more prominent, the humerus at times hanging away from the joint.

Paralysis of the deltoid may be partial or complete, and cases are recorded of reaction of degeneration in parts of the muscle, other parts showing normal reactions. These isolated paralyses result from surgical lesions, more particularly blows, trauma from axillary pads, crutches, pulling on the arm at birth—may all involve the circumflex, or the plexus which gives it origin.

Electric testing of the teres minor is difficult to carry out. Testing of the deltoid is very satisfactory.

Paralysis of the deltoid is usually an obstinate affair. Electric treatment gives excellent results, but there is frequently a residual defect, which often resists for years all attempts at restitution.

Combined Palsies.—The combined palsies due to trunk lesions must be distinguished from those which follow a lesion of the roots of the brachial plexus (*Erb's palsy*). Dislocations of the shoulder-joint, particularly if the head of the humerus should press forward, are responsible for widespread and serious paralyses involving one or more nerve-trunks of the brachial plexus. A diagnosis of the nerves affected may be made from the paralyzed muscles.

Reaction of degeneration soon develops in those muscles most implicated, especially after the period passes when a stage of interstitial edema is apt to cause hard and stiff muscles, for in such a condition reaction of degeneration is difficult to obtain. In many cases of neuritis which may cause extensive atrophies the presence of severe pain may interfere with electric testing and electric treatment for some time.

Erb's Paralysis.—This consists essentially in a lesion of the roots of the brachial plexus, due to a severance or tearing of the root-fibers as they emerge from the spinal cord. As a rule, the chief damage is done to the fifth and sixth cervical nerves, although only the fifth, or only the sixth, or even the seventh, may be disturbed, and the muscles most widely implicated are the deltoid, biceps, supinator brevis, brachialis anticus, and the spinati. At times only the deltoid is involved. There may be associated anesthesia on the outer aspect of the arm, due to the implication of the external cutaneous.

The position of the arm in Erb's *obstetric palsy*, called obstetric because so frequently induced as an obstetric accident—pulling of the arm in delivery with stretching and tearing of nerve-roots—is very characteristic, especially if more than a mere paralysis of a few fibers of the deltoid is present. The arm usually hangs helpless by the side, the forearm being turned inward and backward, so that the palm of the hand is turned backward and even outward.

The electric reactions are of interest in showing the distribution of the implicated fibers, since the biceps, coracobrachialis, and brachialis anticus are supplied by the musculocutaneous, the deltoid is supplied by the circumflex, the supinator longus is supplied by the musculospiral, and the spinati by the suprascapular nerve. In traumatic affections of the musculospiral, and in the neuritides, particularly that of lead, the supinator longus escapes, since the spinal-cord cell-group fibers enter the plexus above the point of fusion that makes up the musculospiral nerve.

Electric testing at *Erb's point—i. e.*, in the neck, about one inch above the clavicle, and a trifle external to the outer border of the sternocleidomastoid, is capable of throwing this entire group of muscles into activity, and when obstetric palsy is present, stimulation at this point is unavailing. In Erb's palsy, also called Duchenne-Erb palsy, other muscles may be involved, and a great degree of complexity is known to occur.

The electric treatment of Erb's palsy by means of both galvanic and faradic currents should be continued for a long time; many mild cases recover spontaneously without treatment, but in the severer cases electric stimulation is of immense service.

Musculospiral Paralysis.—This nerve is most frequently involved outside of the plexus, and causes a loss of power in the extensors of the forearm and wrist and the supinators. The wrist drops, the fingers are flexed but can be extended, if the proximal joint is flexed, by the interossei and the lumbricales. Extension of the elbow is impossible; atrophy of the extensors causes the forearm to shrink very materially, while the bones of the wrist become very apparent. Involvement of the biceps points to injury above the middle of the arm, and supination is then moderately well performed. If supination is entirely gone, the nerve is usually implicated below the middle of the arm. Sensory disturbances are frequent.

The commonest cause of musculospiral paralysis is pressure due to sleeping on the arm, or with the arms hanging over the back of a chair, or poor adjustment of a crutch.

Reaction of degeneration in the various muscles innervated by the musculospiral is sufficient to make a diagnosis of this palsy, and to distinguish it from the wider implications of the brachial plexus in Erb's palsy.

Treatment of musculospiral paralysis by the faradic and galvanic currents is of great service, save in those cases where actual section of the nerve has taken place. The electric currents are of service after the nerve has been united by suture.

Median Nerve.—The median supplies the pronators, the flexor carpi radialis, the flexors of the fingers, and the abductors and flexors of the thumb, and the two radial lumbricales, which flex the first phalanx- It arises from all the roots of the brachial plexus. This nerve may be involved above its muscular branches from wounds in the forearm, fracture of the ulna and radius, injury at the back of the elbow, from pressure of a crutch, or from injury to parts of the plexus. Plexus injuries will not give isolated median-nerve involvement.

The chief symptoms of involvement of the median nerve consist in the loss of ability to flex and to pronate the forearm; this latter is a relative rather than an absolute loss. Flexion to the ulnar side of the wrist is possible. The hand cannot grasp anything well, and the thumb cannot be brought into apposition with the tips of the fingers. It cannot be abducted either. Pain is a frequent symptom, and there is a characteristic anesthesia pictured in works on neurology.

Injuries to the nerve in the wrist causes a paralysis, limited to the movements of the fingers. Atrophy of the thenar eminences is usual.

The median nerve is frequently affected by toxic agents, with resulting neuritis, although this is rarely isolated.

Treatment of paralysis from median-nerve neuritis, or of that due to injury of the nerve-trunk, by means of electric currents differs in no essential respect from the methods to be pursued for other neuritides or paralyses. If electric testing shows the reaction of degeneration to be limited to the distribution of the median, it is highly probable that the injury is due to some mechanic cause.

Ulnar Nerve.—This is derived from the brachial plexus, and is supplied to the flexor profundus digitorum, flexor carpi ulnaris, all the muscles of the little finger, the interossei, two ulnar lumbricales, abductor pollicis, and the flexor brevis pollicis. Many of the muscles of the hand are supplied in part by other nerves, hence there is not a complete loss. A characteristic deformity, the claw hand, is a usual result of ulnar paralysis. The deformity is general, but the third and fourth fingers are most affected.

The ulnar nerve is particularly exposed to damage by reason of its exposed position. Wounds in the forearm, at the wrist, fracture of the ulnar or radius; dislocation, fractures or contusions at the elbow, all may lead to injury of this nerve. Isolated neuritis is known.

Head, Rivers, and Sherrington have shown that the ulnar nerve carries epicritic fibers of touch to one and a half fingers, and the ulnar portion of the palm and dorsum of the hand. It carries sensation of pricking from the little and ring fingers and the palm, save from the thenar eminence, and all the dorsum to the ulnar side of the middle of the middle finger. If the nerve be divided, there is loss of sensibility to cotton-wool over the entire little finger and half of the ring finger, with the same limited area in the palm of the hand. There is also an area which is insensitive to pin-prick over the entire little finger, and a portion of the palm at times very limited, at other times coëxtensive with the area lost to light touch.

Spinal Motor Centers and Motor Nerves of the Lower Extremity

These are less often involved in injuries than are those of the upper limbs, whereas the gray matter in the cord is more apt to be the seat of disease than in the cervical region. In acute poliomyelitis the muscles of the lower limbs are usually affected more than those of the upper extremity, this being particularly true of the peronei. A short consideration will be given to the chief paralyses of the thigh and leg. Their treatment may be considered in one paragraph.

Obturator Nerve.—This is derived from the third and fourth lumbar nerves, and supplies the adductors of the thigh. It is a rare form of palsy, chiefly causing difficulty in crossing one leg over the other and in spreading the legs apart. The disorder is known to follow difficult child-birth, but is usually a transitory affection.

Anterior Crural.—Disease or injury to this nerve in different parts of its course, if within the pelvis, may give rise to loss of power to flex the knee and loss of hip flexion. If outside of the pelvis, flexion of the knee alone is involved. An anesthesia of the entire thigh, save a long V-shaped area in the back of the thigh, is present as well.

Sciatic Nerve.—If this nerve is involved above the middle third of the thigh, the flexors of the knee, the extensors of the hip, and all the muscles below the knee are implicated. If below the upper third, only the muscles below the knee are involved. Paralysis of the sciatic is a comparatively rare affection. Sensory disturbances are, however, very common, and primary neuritis or sciatica is one of the commonest of neuralgic or neuritic affections.

Peroneal Paralysis.—Involvement of the external and internal popliteal nerves causes great loss of the ability to get about. The tibialis anticus, long and short extensors of the toes, and the peronei are all involved in external popliteal injuries. The resulting deformity is foot-drop, with after-developing talipes equinus, due to the unopposed action of the gastrocnemius. As the external popliteal is superficially located it is injured by pressure, by fractures of the fibula, and is occasionally diseased primarily.

The internal popliteal supplies the tibialis posticus and popliteus, as well as the chief muscles of the back of the leg, the long flexors of the toes, and the muscles of the sole of the foot. In injury or disease of this nerve the foot cannot be extended, and the leg cannot be inwardly rotated when flexed if the popliteus is affected. Injury of the internal popliteal takes place in extensive fractures of both bones of the leg.

Plantar Paralysis.—Involvement of the external plantar nerve causes a loss of power in the interossei, the adductor of the big toe, the two outer lumbricales, and the accessory flexor of the foot. Walking is interfered with, the spring having departed from the foot. The toe is apt to strike, and stumbling is usual. The special sensory area is sharply limited.

Injury to the internal plantar nerve brings about a paralysis of the short flexors of the toes, the muscles of the big toe, save the adductor, and the inner lumbricales. It causes a somewhat similar, although much less marked, difficulty in walking.

Treatment.—The electric treatment of these palsies differs in no essential respects from that already outlined in previous paragraphs. In general, one can derive considerable assistance, so far as prognosis is concerned, from the electric reactions. The degree of degeneration which has occurred can be determined, and also the probable length of time necessary for recovery. In all these paralyses, of the lower as well as the upper extremities, the same general rule must be followed as that already outlined. It is necessary in all cases to wait ten days to two weeks for the sake of a diagnosis, as well as a prognosis. In the case of patients where neuritis is found, or in whom painful nerve-trunks may be present apart from neuritis, such as may be due to the irritation of the meninges, too early electric treatment, or even the use of electricity for diagnostic purposes, should be deprecated by reason of the extreme pain which may be induced. If pain be not a prominent feature, the electric reactions should be tested as early as the second week; any earlier is valueless, so far as diagnosis is concerned. In general it may be said that if, at the end of from two to three weeks, we obtain a typic reaction of degeneration, it is probable that the paralysis will persist for at least three months, and may even be found at a much later date—a year or so. If, after three months, no distinct improvement has been observed, it has been generally held that no hopeful outlook can be maintained. This, however, is not the case, for continued and unremitting attention paid to the chronic paralysis will almost invariably result in the restoration of considerable power, at least, and the general rule that if reaction of degeneration is present in a muscle at the end of three months such muscle is doomed, is in need of distinct revision. This may even be said of those reactions of degeneration which are found in paralyzed groups, even after a year, although in such cases the outlook is more gloomy.

If a partial reaction of degeneration is found, or mixed reaction, the chances are much better, and if in the milder cases of neuritis or peripheral palsy due to injury other than actual division of the nerve, a partial reaction of degeneration occurs, the patient will probably recover power in from eight to ten weeks.

If the reaction is simply one of a lessened contractility to faradism and galvanism, the chances of recovery are good, the patient usually recovering full motion, although somewhat diminished in strength, at the end of from four to five weeks.

The methods of application for the electric treatment of paralysis in the lower limbs have already been outlined and are further discussed in the paragraphs on Electromechanotherapy.

All electric treatment should, if possible, be associated with massage and exercises.

Hysteric Paralysis

Faradic currents are used to cause contraction, while at the same time the patient makes a voluntary effort. This forms a sort of re-education. Sensory hysteric paralysis always yields to faradism, with rapid interruptions and a brush electrode. Hysteric amaurosis or more or less contraction of the field of vision are treated by faradization with one of the electrodes applied to the eyelids. Hysteric aphonia is treated by faradism, and usually is quickly cured, though one case of the author's resisted all kinds of treatment, including hypnotic suggestion. Hysteric vomiting is treated by galvanic currents.

Hysteric Contractures.—Faradization with a brush-electrode applied either to the contracted muscle or to its antagonist, and galvanic current with the negative electrode applied to the contracted muscle, bring about a cure.

ELECTROMECHANOTHERAPY

This means the application of electricity to produce muscular contraction. It is useful when, for any reason, it is impossible or undesirable for the patient to exercise his muscles, any particular muscle, or any part of a muscle.

It has, to a greater or less extent, the same beneficial effect upon the nutrition of the muscle and upon the general system that natural exercise produces. Muscular contraction is accompanied by oxidation, generation of heat, and complex processes of tissue activity.

It must be borne in mind that electricity has a specific tonic effect upon muscular as well as other tissues, which it exerts whether muscular contraction is produced or not. This direct effect is more dependent upon the quantity of electricity passed through the muscle than upon abruptness in the change in the strength of the current. The direct effect upon the nutrition of the muscles is produced chiefly by galvanic and sinusoidal currents, and is obtained by forms of application which do not necessarily produce muscular contraction, and also in cases of degeneration in which no contraction can be produced by any form of current.

Confining attention strictly to eletromechanotherapy (the therapeutic production of muscular contraction by electric stimulation), we find it indicated in most muscular paralyses without marked reaction of degeneration. It is sometimes important to avoid stimulation of the antagonistic muscles which respond more readily than the paralyzed ones, and would lead to increased deformity. If this occurs from unipolar stimulation with the indifferent electrode upon the back, it may often be prevented by placing both electrodes on the paralyzed muscle.

The limb should be placed in such a position that contraction of the muscle stimulated will produce a normal movement.

Very often some power of voluntary movement is present, and it is desirable to apply electric stimulation to assist individual attempts at voluntary movement.

As improvement takes place the factor of movement against resistance is to be introduced, making the effect still more like the physiologic effect.

Too long treatments will produce fatigue in the same way as too prolonged natural exercise. This is to be avoided.

Method for *exercising paralyzed muscles by the static induced current* is described on page 494.

Stimulation by galvanic currents is excellent in its trophic or tonic and nutritional effect, and with moderately strong uninterrupted currents, 15 ma., has an excellent effect without causing muscular contraction. To produce the latter the galvanic current must be made and broken and should be much weaker, to prevent discomfort. This involves the loss of some of the benefit obtained from the trophic action of the current.

Galvanic currents are usually applied so as to flow with the physiologic direction of the nerve force. For the treatment of the motor nerves or of the muscles the positive electrode should be near the nerve-center, and the negative electrode should be applied to the motor nerve or to the muscle.

Stimulation by isolated induction shocks produces abrupt muscular contractions, which are better than none, but which are less desirable than if they approached the physiologic type. It gives none of the direct tonic effect of electricity, because the quantity of electricity which passes through the muscle is very small.

Stimulation by condenser discharges is open to the same objection from a therapeutic standpoint, though the certainty with which each discharge may be measured makes it a valuable diagnostic method.

Faradization is the method chiefly employed for electromechanotherapy, but it has the same drawbacks as isolated induction discharges and condenser discharges. The contractions produced by it are not as desirable as physiologic contractions, and the quantity of electricity is too small to produce the direct tonic effect of the current. If the faradic current is employed, it had better be applied with one electrode on the motor nerve or the motor point of the muscle, while the other electrode is on the back or chest or some other indifferent place, and the application be made simply to cause muscular contractions, being supplemented by the galvanic current for its trophic effect.

The **combined effects of faradic and galvanic currents** may be obtained by either their simultaneous or their successive application. The first method will be considered a little later, under the head of Faradogalvanic Currents. The second method is one by which galvanic currents of any desirable strength are applied for ten minutes from electrodes covering the whole affected muscle, either before or after a series of muscular contractions have been excited by the faradic current.

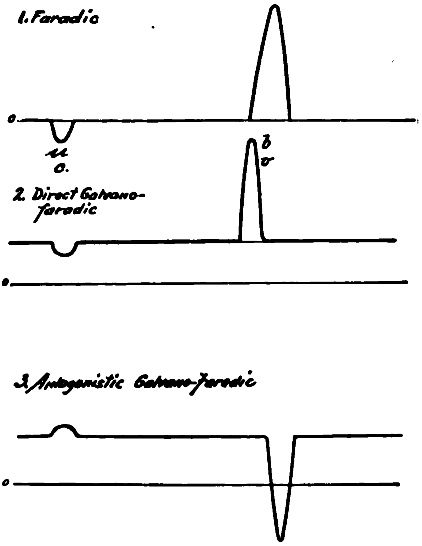

Fig. 301.—Faradic and faradogalvanic currents.

Lewis Jones' experiments show that a faradic coil without an iron core gives currents without such abrupt increase and decrease in strength and produces less abrupt and disagreeable muscular contractions than when the coil has an iron core. Even so modified, however, the faradic coil produces quite an abrupt beginning and end of muscular contraction, with a period of tetanus lasting from the time the current is turned on until it is turned off. This is not at all like the physiologic contraction, and is, therefore, less desirable than the contraction produced by the author's method of rhythmic variation by rheostat and pole-changer, or by the other method of sinusoidal currents with rhythmic variation.

Faradogalvanic or deWatteville currents are applied from an apparatus in which the secondary coil of a faradic coil forms part of the circuit of a galvanic battery. While it has been stated elsewhere that the polarity of a faradic coil makes practically no difference in the physiologic effects, and that either pole may be used as the active electrode, this ceases to be true when the faradic and galvanic currents are combined.

Fig. 301, 1, shows the form of the interrupted currents produced by a faradic coil alone. The make or closure current is of much less strength and is in the opposite direction from the current induced at the break or opening of the primary circuit. The best results are obtained with a galvanofaradic current, when the connections are made so that the opening currents of the faradic coil flow in the same direction as, and add to the strength of, the galvanic current. The proper effect is shown in Fig. 301, 2, and the incorrect effect is shown in Fig. 301, 3.

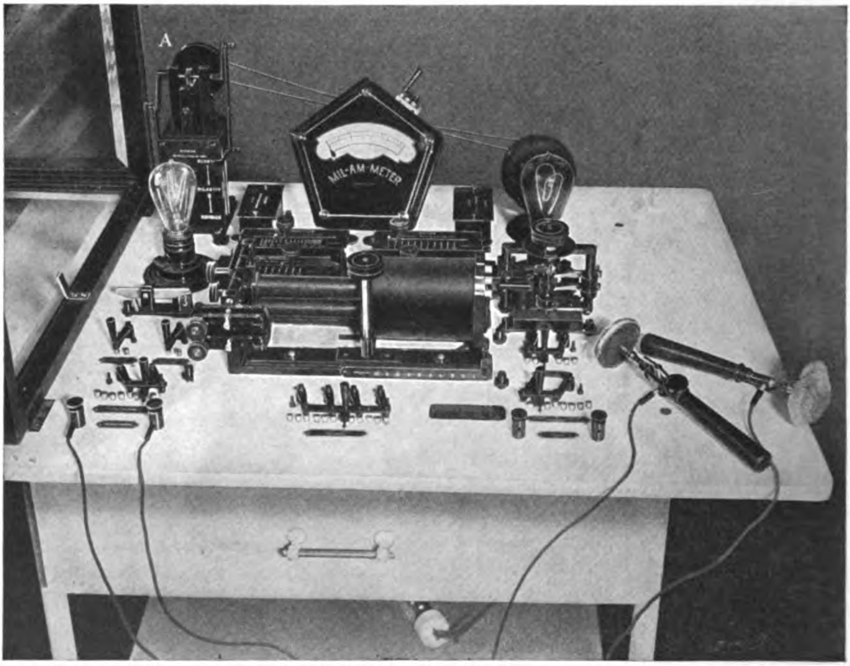

Fig. 302.—Author's galvanic, faradic, and sinusoidal apparatus; giving also galvanofaradic currents, rhythmically interrupted currents, and currents with rhythmic variations in strength and reversals of direction (A).

The sensation produced by galvanofaradization is different from that of either of the component currents separately. Its effect is to cause muscular contraction and trophic stimulation, but applied in the ordinary way by means of a key that makes and breaks the current abruptly the muscular contractions have the same unnatural character as with the simple faradic current.

The *author's method of applying faradogalvanic currents* produces muscular contractions which closely resemble physiologic ones, and makes the application agreeable, and causes it to be followed by a sense of muscular power which is most exhilarating and beneficial. It consists in the use of a *rhythmic rheostat and pole-changer* (Fig. 302, A), by which the direction of the current is reversed at regular intervals of from one-half second to two seconds. There are sliding contacts, which are pushed up and down the rheostat by a small electric motor. At a certain stage the galvanometer will show that no current is passing through the patient. Then, as the rheostat resistance is automatically reduced, the current gradually begins to flow in one direction, and increases to the maximum, 15 ma., perhaps, permitted by the adjustment of another unvarying rheostat and the unvarying volt controller. The latter adjustment had better be made at the commencement of the treatment. In this case it is best to begin with the weakest possible current. After the rhythmically varying rheostat has permitted the maximum desired current to flow, the current is gradually reduced to zero, and is reversed and gradually attains an equal maximum strength in the opposite direction. From here it again gradually returns to zero.

Holding two electrodes in the hands, one feels his grip gradually tighten and relax, first in one hand, and then in the other, as the maximum current is attained in each direction. All the muscles of each upper extremity are affected by the trophic influence of the galvanic current, and the muscular contraction may be caused to involve as many of these muscles as desired by regulating the strength of the faradic current. The application is entirely free from shock and other disagreeable sensations. Its alternating character prevents irritation of the skin by the accumulation of ions, and enables one to secure the beneficial effects of strong currents without having to use enormous electrodes. A good contact is the chief essential. The contractions closely simulate physiologic ones.

These currents are of great value in peripheral paralyses and in constipation, where the electrodes are applied at either side of the abdomen.

The same picture (Fig. 302) shows also the arrangement for utilizing the 110-volt direct current in galvanic, faradic, and deWatteville applications, continuous or interrupted.

In the author's apparatus there are three different secondary windings of the same faradic coil, made instantly available by turning a switch indicating 1500, 3000, or 8000 feet of wire. The ribbon vibrating interrupters regulate the rapidity of the interruptions from the fastest to the slowest, and the two separate primary coils may have the same or different rates of vibration. There is a sledge upon which the single secondary coil may be moved toward or away from the primary coils. The farther away the weaker the current and the physiologic effect.

Gaiffe's Portable Apparatus for Exciting Physiologic Contractions of Muscles.—The apparatus is useful in cases where paralyzed or atrophic muscles are to be exercised in order to maintain their nutrition, but not in cases with the reaction of degeneration. Faradic currents cause muscular contractions which are unnatural in the abruptness with which they begin and end. Voluntary muscular contractions commence gradually, and after attaining their maximum, gradually relax. The apparatus described by Delherm[1] produces contractions of this type by the application of a sinusoidal current, which increases from zero to a maximum strength, and then gradually diminishes to zero.

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[1] Bulletin officiel de la Societe d'Electrotherapie, August, 1907.

The apparatus consists essentially of an electromagnet which oscillates in front of a dynamo, and causes increasing or diminishing currents in the latter. It is portable. Fig. 303, from Delherm, shows the current curve and the wave of muscular contractions obtained with this apparatus. Fig. 304 shows the current curve with isolated induction shocks from a faradic coil and the waves of muscular contraction produced by them. Fig. 305 shows the current wave from the usual faradic current and the tetanic muscular contraction produced by it.

Leduc currents are currents which are uniform and unidirectional, but which are made and broken with a rapid rhythm similar to that of the faradic current. They produce a contraction similar to that from faradic currents, and are open to the same objections as to abruptness of beginning and ending and as to a tetanic condition during the application, and as to the small amount of electricity which traverses the muscle. Leduc currents or any other similarly rapidly interrupted currents of more than 15 ma. would produce intolerable convulsions.

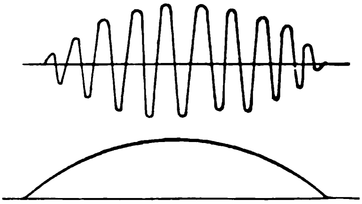

Fig. 303.—Sinusoidal current with rhythmic variation in strength. Muscular contraction similar to physiologic one.

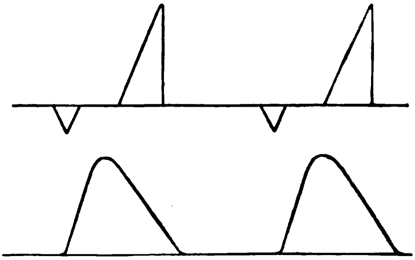

Fig. 304.—Isolated induction shocks. Abrupt muscular contractions.

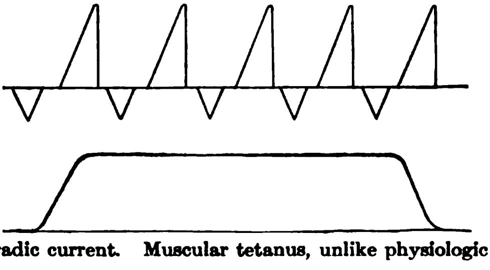

Fig. 305.—Faradic current. Muscular tetanus, unlike physiologic contraction.

These currents have a slight advantage over faradic currents for electromechanotherapy in the fact that the periods of current and the strength of the current can be exactly regulated, and are subject to none of the irregularity present in even the best induction-coil.

Gaiffe's Large Apparatus for Electromechanotherapy.—The apparatus (Fig. 306) has a primary coil through which passes an alternating current which may be taken from the alternating electric-light circuit and the strength of which is regulated by a volt-controller. No interrupter is required; the alternating current in the primary generates a sinusoidal current in the secondary coil. The latter is pushed back and forth by an electric motor, and when it is immediately around the primary coil, generates a stronger secondary current than when it is removed from it. The adjustment may be such that during any desired fraction of each period the secondary coil is entirely removed from around the primary coil, and the secondary current is so weak as to produce no muscular contraction. The intervals of rest between the muscular contractions may, therefore, be as long as desired. The muscular contractions are excited at regular intervals, commence and end gradually, and are very much like physiologic contractions. The amount of electricity which flows through the muscle may be measured by a milliamperemeter. It is sufficient to produce the trophic effect of electricity.

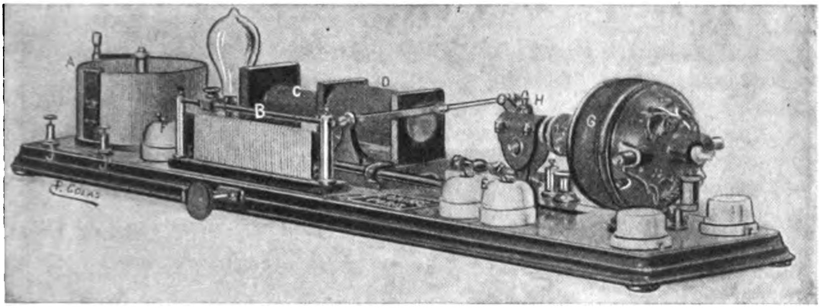

Fig. 306.—Gaiffe's large apparatus for electromechanotherapy.

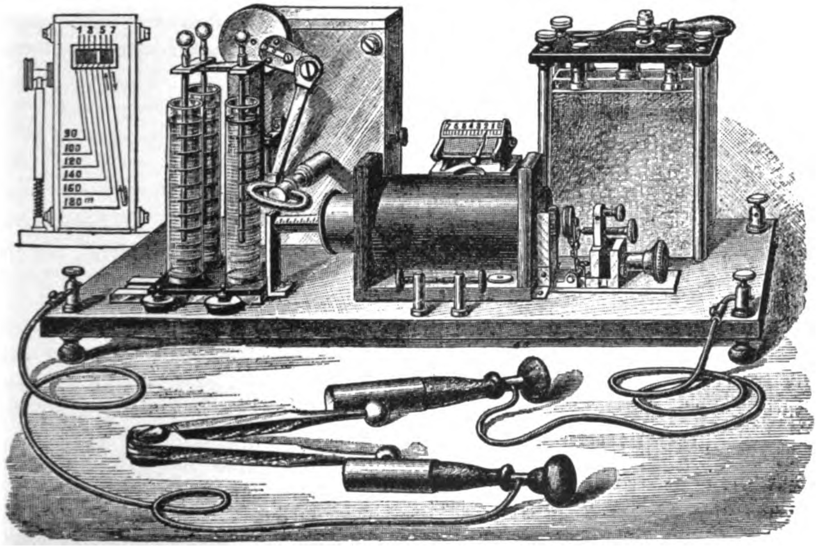

Fig. 307.—Enallaxotone current apparatus.

The Enallaxotone Current.—This is the name given to a modification of the faradic current suggested by Nicoletis.[1] It depends upon the transmission of the induced current from a regular faradic battery through a liquid rheostat, with a variable distance between the electrodes. At certain periods in the motion of these electrodes there is practically no current, while at other periods almost the full intensity of the current reaches the patient. There is consequently an undulatory contraction in muscles to which sponge electrodes are applied.

An Automatic Rhythmic Rheotome for Galvanic, Faradic, and deWatteville Currents.—One terminal is fixed in position, while the other can swing around horizontally in almost a complete circle, and is normally pressed against the other by the action of a spring resembling the hair-spring of a watch. An electromagnet is placed in a vertical position near an iron bar on the revolving contact, but at a lower level, so that the revolving contact can swing back and forth over it. When the current is turned on, the electromagnet attracts the iron bar and breaks the contact. The current ceasing, the electromagnet ceases to attract, and the spring swings the iron bar back into contact again. The rapidity of interruption may be varied from 80 to 2000 times a minute. This is done by the adjustment of a stop which regulates the distance to which the iron bar may swing away from the point of contact. This apparatus forms part of the author's table for utilizing the 110-volt direct electric current for galvanic and faradic currents and for diagnostic illumination (Fig. 302, p. 470).

Unidirectional Undulatory Currents of Low Potential.—Bordier's observations[2] lead him to the conclusion that these currents represented by the curve in Fig. 288 are even better in their effect upon muscular atrophy than the rhythmic, gradually alternating currents given by the apparatus (p. 470) employed by the author. The apparatus for producing these currents differs very little in appearance from the one alluded to. It consists of a rheostat with a sliding contact, which is moved back and forth from the zero-point by an electric motor.

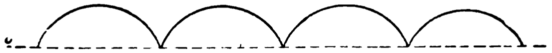

Fig. 308.—Unidirectional undulatory current.

The *physiologic effects of the application of these currents to muscles and motor nerves* are quite different from those of ordinary galvanic currents made and broken by a key, or by the *metronome interrupter*. The indifferent electrode should be a large plate, measuring 5 by 8 inches, and covered with several layers of damp cloth and placed under the patient's back. The active electrode usually connected with the negative pole is a sponge electrode, 2½ inches in diameter. The speed of the motor is varied so that it takes from one to two seconds for the change from zero to a maximum current, and an equal length of time for a return to zero. The contraction which occurs is of a gradual character, like a physiologic contraction. The strength of the current required to produce muscular contraction in healthy muscles is greater than with sudden makes and breaks of the galvanic current, and in atrophic muscles as much as 10 to 50 ma. may be required. These

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[1] Journal Physiotherapie, November 15, 1907.
[2] Arch. d'elect. med., June 25, 1905.

heavy currents have been used by Bordet,[1] who found that they cause a slight burning sensation which the patient can stand, instead of the severe burning feeling from the ordinary galvanic applications. The more atrophic the muscle is, the stronger the current required. As to the speed of the undulations in the current, the more natural the muscle, the more rapid speed is required to produce contraction. The muscle contracts gradually in its entire mass, and the contraction is limited to that particular muscle. Bordet produced an increase of size and strength in the biceps of healthy men by applying these currents to that muscle. The strength of current was 10 ma.; 100 waves of current were applied every day for fifty or sixty days, with an increase of 2 or 3 cm. (0.8 inch or 1.2 inches) in circumference. This was a slightly greater increase than was produced on the other arms of the same subjects by a rhythmic undulatory galvanic current with a change of polarity.

These currents are valuable in the treatment of muscular atrophy.

Leduc Currents.—*Leduc's Apparatus for Low-tension Interrupted Currents.*[2]—The constant current from a galvanic battery, a storage-battery, or a dynamo is interrupted by a wheel interrupter, which is kept in revolution by an electric motor. The interrupter is placed in series, so that one wire from the battery leads to the interrupter, and a wire leads from the interrupter to one of the electrodes applied to the patient. The wire from the other electrode applied to the patient leads to the other pole of the battery.

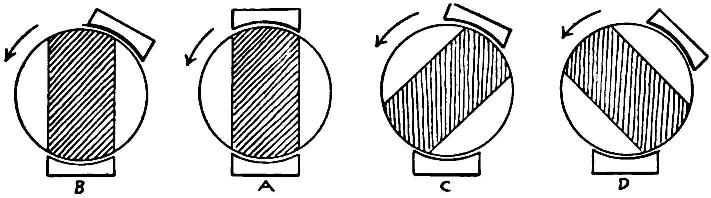

Fig. 309.—Leduc interrupter.

The wire leading from the battery to the interrupter is connected with a stationary brush which has a broad surface for contact with the rim of a revolving disk. The latter consists of metal, but has two insulated sections at opposite sides. The wire leading away from the interrupter is connected with another brush contact, the position of which is adjustable. When the movable brush is directly opposite the fixed one, as in Fig. 309, A, both brushes are in contact with the conducting part of the disk at the same time and for the same length of time. As the disk revolves at a uniform speed, the current flows for a certain length of time and then ceases to flow for a certain length of time. These periods of current and absence of current are exactly proportional in duration to the length of the conducting and the insulated portions of the circumference of the wheel.

Displacing the movable brush (as in B, Fig. 309) so that when every part of the fixed brush is in contact with one end of the conducting section, while only half of the movable brush is in contact with the other end, produces a change in the relative duration of the periods of current and no current. With the same speed of rotation the

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[1] Arch. d'elect. med., June 25, 1907.
[2] Ibid., September 15, 1903.

periods of current are only half as long as before, and the periods of no current are increased by a certain fraction. Reference to diagrams C and D (Fig. 309) shows that while the current begins to flow as soon as the contact is made with the stationary brush, it is arrested before contact with the stationary brush has ceased.

Different positions of the movable brush give periods of current flow which are equal to, or are only $\frac{1}{2}$, $\frac{1}{5}$, $\frac{1}{10}$, $\frac{1}{20}$, or $\frac{1}{100}$ the duration of the periods of current arrest.

The number of periods per minute is varied by a rheostat controlling the motor which turns the wheel of the interrupter.

The strength of current flowing during the periods of contact is regulated by the ordinary means. In the case of a galvanic battery, one can use a cell selector, regulating the number of cells in series or in parallel or a rheostat regulating the outside resistance. A rheostat will generally be required with a storage-battery. Both a rheostat and a volt-controller or shunt are generally required when the 110-volt direct electric-light current is used.

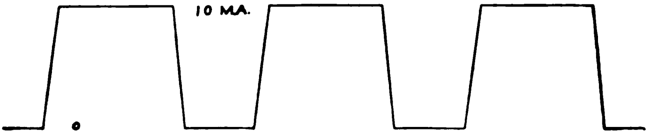

Fig. 310.—Character of Leduc currents.

The strength of current ordinarily required is less than with the galvanic current—usually from $\frac{1}{10}$ to 15 ma. The maximum strength of 50 to 80 or more ma. sometimes used with the galvanic current is never to be used with the Leduc currents. The effect of the latter is that of a series of abrupt makes and breaks, and this would be exceedingly disagreeable, and perhaps dangerous, with strong currents.

The current strength may be measured by an aperiodic galvanometer. This will indicate fairly well the average or effective strength of the current, and from this and the relation between the periods of flow and arrest one may, if desired, calculate the absolute strength of the current when actually flowing.

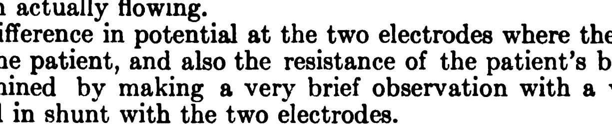

Fig. 311.—Character of faradic current from a long secondary coil with an iron core.

The difference in potential at the two electrodes where they are applied to the patient, and also the resistance of the patient's body, may be determined by making a very brief observation with a voltmeter connected in shunt with the two electrodes.

Character of Leduc Currents.—Each successive period gives the same known strength of current flowing for the same length of time and in the same direction.

Difference Between Leduc and Faradic Currents (Figs. 310 and 311).—The faradic currents, on the other hand, show periods of current in alternate directions, and the strength and duration of the successive impulses, and even their periodicity, vary in consequence of imperfect action of the vibrating interrupter. The latter may not make perfect contacts every time.

Advantages and Disadvantages of Leduc Currents as Compared with Faradic Currents.—The advantages are chiefly due to the fact that the successive currents are of the same known strength and occur at a known rate per minute. The muscular response, a tetanic contraction lasting as long as the interrupted current is turned on, is similar to that produced by faradic currents, but electrodiagnosis is much more exact with the Leduc currents. It is also easier to make accurate comparisons between reported cases and the one under observation.

The disadvantage is that the successive currents are all in the same direction, and the same polarization occurs which has such a tendency to vitiate measurements and cause irritation when the galvanic current is used. The faradic current is alternating, and is not open to this objection. This objection to the Leduc current may be overcome by the occasional use of the pole-changer, without which no electric apparatus can be considered complete, or by the use of an apparatus giving alternating Leduc currents, or, best of all, by transmitting the Leduc currents through the author's rhythmic rheostat and pole-changer.

The Leduc apparatus may, therefore, be considered a most valuable improvement over the faradic coil for diagnostic purposes. Its advantages for treatment are not so well established, although Leduc's "electric sleep" is thought to be a condition produced by the interrupted unidirectional current which the alternating discharge from a faradic coil will not produce. There is no doubt at all that the utmost regularity in the successive currents is desirable in every case, but unidirectional currents may not always be preferable to alternating ones. The fact that the induced currents from a faradic coil have a higher voltage than that of the direct primary current in the same coil does not enter into the problem. The Leduc apparatus allows of the application of currents of equally high tension. Both the Leduc and the faradic currents are, however, known as low-tension currents. High tension is a term that applies more properly to the discharge from a static machine, an Oudin resonator, or a Ruhmkorff coil. It means a sparking distance measured in inches, not in thousandths of an inch, as in the Leduc and the faradic currents.

Leduc has found that the most effective stimulation of muscular contraction is obtained when the duration of the passage of the current is $\frac{1}{1000}$ second each time. Adjusting the apparatus for this length of current waves and for a frequency of 100 periods a second, it is simply necessary to determine the voltage necessary to excite muscular contraction; or, what is sometimes more convenient, the milliamperage required with electrodes of a certain area of contact.

The contractions ordinarily elicited by electricity are due to the closing and opening of the circuit, and not to a uniform flow or absence of current. They seem to be due to the variable period of the current; a very short, but still a measurable length of time during which the current is increasing from zero to its maximum strength or diminishing to zero.

The variable period of the current at the closure of a galvanic circuit has been found by Blaserna to be 0.00048 second, and at the opening of the circuit it is 0.00027 second.

These facts seem to throw some doubt upon the value of the chief feature of the Leduc currents—*i. e.*, the ability to regulate the exact duration of the successive periods of current flow, but this is hardly a correct view of the case. Though the period during which the current flows uniformly is a period without practical physiologic effect, its duration directly controls the length of time between the physiologic effect due to the closure and that due to the opening of the circuit, and we know what a very great influence rapidity of succession in electric impulses exerts upon physiologic effect.

BEGINNING OF MUSCULAR REACTION WITH LEDUC CURRENTS

PERIOD.	VOLTS.	TIME OF PASSAGE OF CURRENT IN SECONDS.
$\frac{1}{1000}$	22	0.00001
$\frac{10}{1000}$	15	0.0001
$\frac{20}{1000}$	15	0.0002
$\frac{30}{1000}$	12	0.0003
$\frac{40}{1000}$	11.5	0.0004
$\frac{50}{1000}$	10.5	0.0005
$\frac{60}{1000}$	9.5	0.0006
$\frac{70}{1000}$	9	0.0007
$\frac{90}{1000}$	8.5	0.0009
$\frac{100}{1000}$	7	0.001

Effect of Leduc Currents upon Animal Development and Nutrition.—In experiments by Bordier and Bonnenfant[1] the negative electrode was placed at the nucha and the positive electrode over the sacrum; the skin was shaved.

Rabbits about three weeks old were treated every other day. The interruptions were 3720 a minute. The first rabbit experimented upon had convulsions and fell over on its side with a current of 18 ma. The current was then reduced to 8 ma., and allowed to flow for ten minutes. At the second such treatment the rabbit died, probably from compression of the trachea by an elastic band used to hold the electrode in place. Other rabbits showed complete anesthesia and a somewhat accelerated respiration with a current of 18 ma., and this was followed by 8 ma. for ten minutes. The animal showed no bad effects. Subsequent applications to this rabbit were 15 ma. at the start, followed by 8 ma. for ten minutes. Only twice during the two months' course of treatment did the rabbit show any bad effects. On these occasions there was transitory paralysis of both legs. The result was that while the rabbit experimented upon had in the beginning weighed 15 grams more than the control rabbit which was not treated, it weighed 100 grams less than the other at the end of two months. It had grown, but not so fast as if it had not been treated by electricity. During a week's intermission in the treatment it grew faster than the other rabbit.

Adult rabbits weighing over 3 kilograms were treated in the same way. The current was interrupted 4320 times a minute, and was run up to 35 or 40 ma. at first to produce anesthesia, and was kept at 10 ma. for ten minutes. These treatments were given every day for twenty-four days, with a result that there was a reduction of 10 per cent. in the weight of the animal, and a change in the radiation of heat from 1500 to 3000 calories per hour.

The current of electricity flowed during two-thirds of every period

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[1] Arch. d'electricité medicale, April 25, 1905.

of the interrupter, and each ten minutes' treatment at 8 ma. equaled $3\frac{2}{10}$ coulombs; and at 10 ma. equaled 4 coulombs.

These results may find a practical application in the treatment of obesity.

They certainly show that a long course of treatment by these rapidly interrupted galvanic currents should not generally be applied in the case of growing children. This applies more particularly to treatment applied in such a way that the spinal cord acts as the principal conducting path.

PRACTICAL EXAMPLES OF THE USE OF CONDENSERS IN ELECTRO-THERAPEUTICS

IN CONNECTION WITH THE STATIC ELECTRIC MACHINE

To Apply the Static Induced Current (Fig. 312).—The inner armatures of two Leyden jars are connected with the two poles of the static machine, while electrodes connected with the outer armatures are applied to the patient. Each time the inner armatures are charged, a current is induced through the patient in one direction. And when the inner armatures are discharged by the passage of a spark between the two discharging rods of the static machine, a current passes through the patient in a direction opposite to that of the charging current. The inner armature of the jar connected with the positive pole of the static machine becomes charged with positive electricity, and by induction repels positive electricity from the outer armature of the same Leyden jar through the patient to the outer armature of the other jar. Negative electricity is repelled from the outer armature of the jar connected with the negative pole of the static machine through the patient to the other jar. On the discharge of the Leyden jars the charges on the external armatures are released and pass in the opposite direction. It is convenient to speak of the direction in which the positive charge passes as the direction of the current, and this is from the jar connected with the positive pole while the Leyden jars are becoming charged, and in the opposite direction while they are being discharged by the passage of a spark. The rapidity of the alternations is not very great—it is merely that of sparks, and they may be readily counted. The quantity of electricity transmitted through the body depends principally upon the size of the Leyden jars, while its tension depends principally upon the length of the spark-gap and, of course, is limited by the power of the static machine.

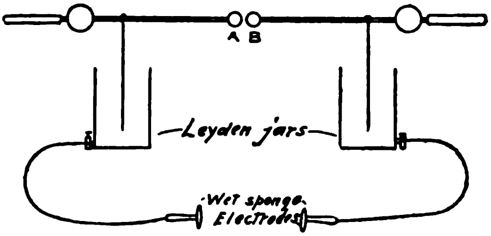

Fig. 312.—Static induced current, regulated by slowly separating A and B.

An **isolated condenser spark** may be applied from a small Leyden jar already charged. The patient is not insulated, and the external armature of the Leyden jar is connected with the ground, while the other pole, the brass knob connected with the inner armature of the Leyden jar, is brought near the patient (Fig. 313). A spark passes to the patient, and produces physiologic effects which are of diagnostic and therapeutic value, and especially so from the fact that the spark can be applied exactly to the desired spot, and can be perfectly regulated as to volume and consequently as to voltage. The author's technic is to have the patient seated or standing or lying about 3 feet from the static machine, but not upon an insulated platform. The operator holds a Leyden jar, his fingers grasping the outer metal coating. A wire or chain which need not be insulated is fastened to the outer coating, and at its other extremity to a water or gas-pipe, which effectually grounds it. The static machine is to be in operation, and its discharging rods are to be fixed at a certain distance apart, and this regulates the voltage of the charge. The latter cannot exceed the amount required to spark across the air-space between the discharging rods. The Leyden jar is held so that the inner electrode, that is, the brass rod connected with the inner metal coating or armature, touches one of the discharging rods of the static machine. It takes only a short time completely to charge the Leyden jar, and it remains charged until the inner electrode is applied to the patient. A spark is then produced, the patient and the earth completing the connection between the internal and external armatures. From the standpoint of convenience in handling, as well as with regard to the physiologic effect, the appropriate size of Leyden jar is one consisting of a glass bottle 10 inches long and about 2½ inches in diameter, with external and internal armatures covering the bottom, and extending 3½ inches up on the sides of the jar. The operator experiences no sensation either when charging the jar or when applying the spark to the patient. The capacity of the same Leyden jar is, of course, always the same, but the quantity of electricity which it takes to charge this capacity, as well as its tension, is increased when the distance between the discharging rods of the static machine is increased. This distance should be ½ inch at the commencement of the examination or treatment, and may be gradually increased to 1, or possibly 2 inches, depending upon the nature of the case, the sensitiveness of the region to which the spark is applied, and the individuality of the patient. The spark may be applied through the clothes or directly to the skin. Isolated condenser discharges may be applied in rapid succession, and every one be perfectly regulated. Almost any type of

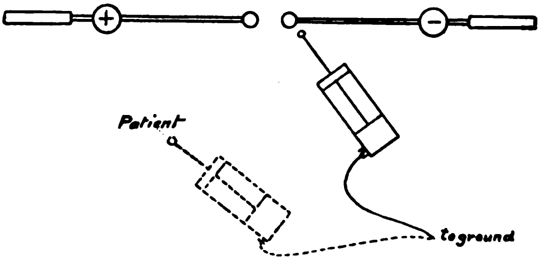

Fig. 313.—Isolated Leyden jar spark applied to patient.

static machine will charge a Leyden jar amply for this purpose. It does not require one of the large glass-encased machines with eight to sixteen or twenty glass plates used for the generation of the *x*-ray.

Condensers for stimulating muscles or nerves have a capacity of $\frac{1}{1000}$, $\frac{1}{100}$, or, at the most, $\frac{1}{10}$ microfarad.

The Leyden jar cannot be successfully charged for use in exactly this way, either from an induction-coil or a transformer. The alternating character of the impulses prevents the armature which is applied to one pole of the coil from receiving a permanent charge of either positive or negative electricity.

Leyden Jars or Other Condensers as an Essential Part of High-frequency Apparatus.—A single example will suffice to illustrate this use of the condenser principle. Fig. 314 shows a form of resonator employed by the author. P and P′ are the poles of an *x*-ray coil or an *x*-ray transformer, whose discharging rods or spintremeter are wide apart. A conducting cord passes from each pole of the coil to the internal armature of a Leyden jar, and between the internal armatures of the two jars there is an adjustable spark-gap, S. G., surrounded by a glass cylinder to muffle its noise. The external armatures of the two jars are connected one to the beginning of a flat spiral of insulated wire, and the other to the second, third, or fourth turn of the spiral, according to the effect desired. The internal armatures of the jars act as large capacities because each forms part of a condenser. A sufficient output is required from the coil or transformer to overcharge the Leyden jars at each impulse from the coil. Taking the right-hand jar, for instance, its internal armature receives at a certain instant a positive charge which drives the positive electricity from its external armature through the desired number of turns in the spiral resonator to the outer armature of the other jar. At the same instant the internal armature of the other jar has received a negative charge, and the negative electricity is repelled from its outer armature through the resonator to the outer armature of the other jar. The result is that the outer armature of one Leyden jar is charged with positive and that of the other jar with negative elec-

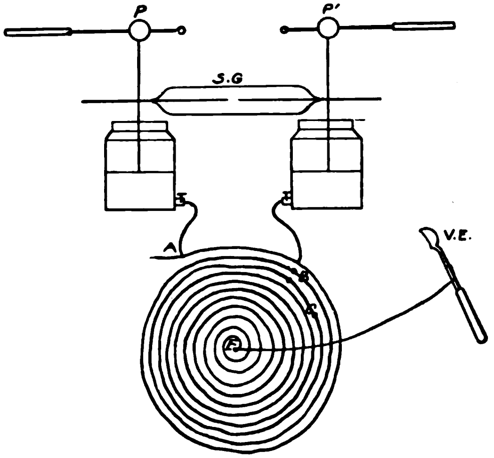

Fig. 314.—Leyden jars as part of apparatus for generating high-frequency currents.

tricity. Though there is a complete metallic connection between these two opposite charges through the wire of the resonator, they are held bound upon the surface of the glass by the charges upon the inner armatures. When the latter are discharged by a disruptive discharge across the spark-gap, and the charges on the external armatures are liberated, a discharge at once takes place through the resonator turns, and this is of the same high-frequency character always found in a discharge of static electricity, and especially the discharge of a Leyden jar. Thousands of oscillations occur in the conductor through which the discharge takes place in the small fraction of a second required completely to neutralize the two opposite charges. The term high frequency refers to these millions of oscillations each second, not to the few score, or possibly a few thousand, disruptive discharges a minute which are directly visible and audible at the spark-gap. The condenser stores up the energy of each current induced in the secondary of the induction-coil or transformer, and gives it what may be called a *static quality*, resulting in inconceivably rapid oscillations each time that a discharge occurs.

The resonator or spiral wire acts as a self-inductance, and increases the voltage of the electricity supplied to it, so that an effluve from 1 to 4 inches long may be obtained at the electrode.

The condensers act in the same way in all the high-frequency apparatus, in connection with resonators and solenoids of different types. These act either to increase the electromotive force, or as choke coils to reduce it, or again, in autoconduction cages, to induce high-frequency currents in the patient.

Condenser Electrodes.—These are especially useful in the application of high-frequency currents. Fig. 315 shows one type with a leading-in wire and a metallic rod extending down through the middle of a glass tube, which is closed at the extremity. The tube contains air or other gas which may or may not be partially exhausted. When this electrode is applied to the skin or to a mucous membrane, the patient's body becomes the external armature of the condenser. The glass and air of the tube form the dielectric and the metal rod the inner armature. Another condenser electrode (Fig. 316) consists of a metal rod with a hard-rubber covering.

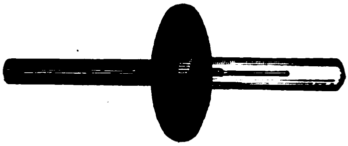

Fig. 315.—A condenser electrode.

Fig. 316.—A condenser electrode.

The ordinary vacuum electrodes (Fig. 317) for high-frequency currents have a similar principle. If they have a leading-in wire the communication of the high-frequency charge to the contents of the tube is perfectly direct. If there is no wire, the metal socket of the handle forms one armature of a condenser in which the dielectric is formed by the glass wall of the tube where it is in contact with the metal socket. The handle is charged with positive and negative electricity in exceedingly rapid succession, and with each positive charge of the handle the positive charge of the inner armature, the contained partially rarefied gas, is repelled. With each negative charge of the handle the positive charge of the gaseous contents surges back to a point within the glass tube where it is separated from the charged handle by only the thickness of the glass. At the other extremity of the vacuum tube a similar inductive action is produced; the positive charge repelled from the region of the handle forms the positive charge of a condenser whose inner armature is the rarefied gas, whose dielectric is the glass wall of the tube, and whose external armature is the surface of the patient. The latter receives by induction a negative charge, negative electricity in the patient's body being attracted to the surface of the glass dielectric, and positive electricity being repelled to the most distant possible part of the patient's body. With the exceedingly rapid alternations in polarity which characterize the high-frequency current, electrostatic charges surge back and forth through the patient's body. These originate in and are concentrated at the surface of contact with the vacuum electrode, where the local effect is, therefore, greatest. They extend to every portion of the body, as can be easily demonstrated by touching any part of the patient lightly with the tip of the finger-nail. The characteristic violet light is seen between the finger and the patient, and there is a slight smarting sensation from the passage of innumerable microscopic sparks. The experiment produces no shock or muscular contraction, and none of the sensation which has so long been associated with the name of electricity. Chemic changes produced by the current in the deepest tissues show that the charge is not limited, as in the case of static electricity, to the surface of the body, but that it also penetrates every portion of the body.

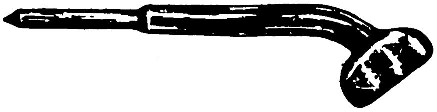

Fig. 317.—A vacuum electrode.

Another type of condenser electrode is made by filling a glass tube with a liquid which is a good conductor, or by coating its interior with metal. Condenser electrodes filled with salt solution have a greater electric capacity than vacuum electrodes of the same size and shape. They give a somewhat stronger current with the same adjustment of the high-frequency apparatus, but do not themselves become hot, as do the vacuum electrodes. This is a noteworthy advantage over the latter. They are not liable to be ruined by breaking down of the vacuum, leakage that is, which is practically impossible to repair in the case of a vacuum electrode, and which is usually the result of overheating at the handle or of an excessive current puncturing the dielectric, or of mechanic violence, screwing the handle on too tight, or knocking the tube against some hard object. This type of condenser electrode does not get hot; it does not contain a vacuum; and is, therefore, not affected by a minute fissure which would terminate the usefulness of a vacuum electrode.

It does not contain a space filled with violet light and ultraviolet rays, but, like the vacuum electrode, it generates a certain amount of ultraviolet rays where minute sparks pass between the glass and the surface of the patient. In other respects its effects seem to be identical with those of the vacuum electrode.

The Reason Why a Glass Tube which Has Lost its Vacuum Does Not Act as a Condenser Electrode.—In the first place, a glass tube which has not been exhausted, but which has only a small fraction of an inch of air between the glass in contact with the patient and the charged wire or other conductor, really does act as a good condenser electrode for

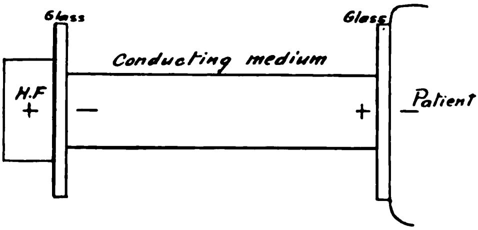

Fig. 318.—Principle of the vacuum electrode in contact with the patient.

high-frequency currents. Such an electrode may consist of a glass tube sealed at the end applied to the patient, and having a wire extending practically its whole length. A small thickness of air acts as part of the dielectric, the other part being the glass wall, and the two armatures being the wire and the patient.

The ordinary vacuum electrode presents quite different conditions. There is a long space of perhaps as much as 6 inches between the glass in contact with the patient and the charged metal handle or leading-in wire. Electric induction cannot take place to a sufficient extent in a condenser having a dielectric 6 inches thick, and air at the ordinary

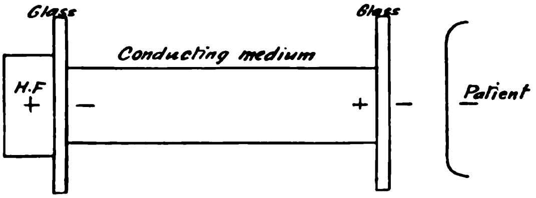

Fig. 319.—Principle of the vacuum electrode held at sparking distance from the patient.

pressure will not act as a conductor of electricity unless ionized. And even then it is not a sufficiently good conductor for this purpose. The vacuum electrode contains air or other gas at a pressure of $\frac{1}{1000}$ atmosphere, the Geissler degree of vacuum, which is an excellent conductor of the high-frequency current.

The *operation of the condenser electrode* may be diagrammatically shown as in Fig. 318. At a certain instant the metallic handle from the high-frequency apparatus may have a positive charge. It induces, through the glass at that point, a negative charge in the conducting medium, *e. g.*, rarefied air or saline solution, contained in the tube, and consequently a positive charge in the distal portion of the conducting medium. There again a condenser action occurs inducing a negative charge in the portion of the patient in contact with the glass. At the next instant the polarity is reversed at every point in the series.

The Operation of the Condenser Electrode When at Some Distance from the Patient.—Fig. 319 shows this in a diagrammatic way. At the instant that the distal portion of the conducting medium is charged with positive electricity, a condenser action takes place, producing through the glass and open-air dielectric a strong negative charge in the nearest portion of the patient. If the air-space is only a fraction of an inch, this negative charge will break through the layer of air as an effluve or as a shower of sparks, as the case may be. In the diagram a negative charge is shown to have accumulated in this way upon the surface of the glass, held there just as in the "dissected Leyden jar."

THE USE OF CONDENSERS IN CONNECTION WITH INDUCTION-COILS

This is of the greatest importance, and has been considered on p. 139.

NEURALGIA AND NEURITIS

Satisfactory distinctions between the neuralgias and neuritides are not easy to draw. The severe neuralgias pass over into mild or severe neuritides, whereas, the mild neuritides may be considered as neuralgias. It is largely a question of degree. So far as the severe neuritides are concerned, however, certain grave alterations are found in the nerve-trunks which are not known to exist in neuralgias. Such are cell infiltrations in and about the nerve-fibers, proliferation of new connective tissue causing pressure, and various degenerations which are usually peripheral, but which also may be interpreted as central in origin.

The chief neuralgias which are amenable to electric treatment and which the electric therapeutist is oftenest called upon to treat are those of the trigeminal, brachial, the musculocutaneous, and the sciatic nerves. There are other neuralgias, such as ovarian, coccygeal, the neuralgias of herpes, etc., which occasionally call for electric treatment, but in general those of the facial region, brachial, and of the sciatic distribution are the most obstinate.

In the consideration of the treatment of the neuralgias one should bear in mind always the question of referred pains. These referred pains have been so exhaustively studied by Head, Dana, McKenzie, and others that we are now in a position to refer the vast majority of the so-called neuralgias to certain disturbances in the viscera. These visceral disturbances, as is well known, send or cause nerve impulses to travel to the spinal cord, which, coming in some sort of contact with certain sensory nerves in the spinal segment, are referred to the skin area of these segmental nerves.

These skin areas have been very accurately mapped out by the researches of the authors mentioned, and it is well known, through these researches, that the whole surface of the body may be divided into areas which correspond to or represent the cutaneous surface in contact with the nerves of the visceral organs. This leads to the development of cutaneous tenderness in practically all referred pains, and this is a very essential factor in the diagnosis of this type of so-called neuralgias. These cutaneous tendernesses have a marked feature in contrast with the pains, which are perceptible over the area of a nerve-trunk, such as are frequently seen in the neuritides.

Thus in the investigation of the neuralgias special care must be taken, first, to outline the importance of visceral diseases; secondly, to determine if such neuralgias may be due to growths on or pressing upon the nerve-trunks; and, finally, to consider the specific type of herpes neuralgias which are due to the involvement in the posterior ganglion. It should be borne in mind that such involvement in the posterior ganglion may set up very severe neuralgias without a corresponding herpetic eruption, although, as a rule, a skin eruption is apt to follow the inflammation of the posterior root ganglion. These herpetic areas are clearly outlined in works on neuralgia, and the relation of visceral disease to herpetic inflammation is one of the most interesting chapters connected with sensory localization.

The electric treatment, therefore, of the different neuralgias must take into consideration the manifold origin of these affections. The treatment of neuralgias due to visceral diseases—in other words, the referred pain neuralgias—consists essentially in the use of electricity as a counterirritant, the counterirritant being applied, if possible, in the area corresponding to the viscus affected. Medical treatment of the viscus should not be overlooked, being often of more value than the electric treatment of its reflection only, so to speak.

Referred pains in the head, neck, and face are frequently the result of disease of the nose, the eye, the ear, the tongue, the teeth, the tonsils, the larynx, or of the brain itself. Finally, a number of the internal viscera, such as those of the thorax and abdomen, which receive their nerve-supply from the vagus or the glossopharyngeal nerves, are capable of inducing referred pains in and about the head and neck, and some very persistent neuralgias of the face are often due to disease of viscera below the diaphragm.

Electric Treatment of Neuritis.—In cases of neuritis the nerve is usually to be treated by galvanic currents; the paralyzed muscles, by faradization or galvanofaradization.

Sinusoidal currents may be applied in the same way as faradic or galvanofaradic currents, and often succeed in cases of neuritis where these currents have failed.

Static Induced Sparks for Neuralgia.—These are applied by a metal electrode through the intermediary of a static regulator. Direct static sparks are also useful.

Trigeminal Neuralgia.—The most persistent of all the neuralgias of the face is that known so widely as tic douloureux. This belongs to the group of neuralgias due to disease of the sensory ganglion. It differs, somewhat, although not always, from the ordinary herpes neuralgias in that it is more persistent, more severe, is usually not associated with paralysis, and does not cause an herpetic eruption. This is not an absolute rule, but is the general course of the disease. Any one of the chief branches of the fifth nerve may be involved, and in the more protracted cases it is usual to find that all the distribution of the fifth nerve is implicated, and in the chronic cases certain trophic changes usually accompany the onward progress of the disease.

Ordinary faradic or galvanic electricity, more particularly faradic, is practically of no value in the treatment of trigeminal neuralgia, save perhaps in the very early stages. The principle of a counterirritant does not apply to these cases, as it does to the treatment of referred pains. Certain modifications of electric treatment, however, have proved of service in this persistent form of neuralgia. Thus high-frequency currents and high-voltage currents have shown themselves to be of value, and the treatments advised by Bergonié and Leduc have been reported as efficacious. Leduc[1] has reported an interesting case in which he has been able to apply, by the method of cataphoresis, the ions of quinin with permanent relief. The case was that of a woman sixty-eight years of age, who developed a tic douloureux after refrigeration. The inferior branch alone was involved. The area was exquisitely tender, and the slightest variation in temperature caused a paroxysm. She was unable to swallow anything cold, and even the blowing of cool air upon her face was unbearable. She was unable to sleep, her teeth were sacrificed to no advantage, and the submaxillary nerve was divided and the lower jaw resected without results. Bichlorid of quinin in 1 per cent. solution was applied electrically for half an hour, with a current which was gradually raised to 20 ma. This gave rise to redness in the skin and edema, but there was a marked diminution in the pain, and the patient was able to sleep. A second application was made three days later, since which time (one month after the application) there had been no return of the pain. Leduc has never given the subsequent history of this case, and it is certain that to report such a case one month after does not prove the permanent efficacy of cataphoresis in the treatment of this affection.

Bergonié has advised a method of applying very heavy currents by means of electrodes which cover the entire side of the face. The current is applied in as large doses as from 60 to 80 ma., the active electrode (aluminum electrode covered with damp wadding or clay) being the positive pole, and being very accurately fitted to the surface and modeling of the face. The duration of the application should be at least half an hour.

Bergonié's Method for Trigeminal Neuralgia.—Correct technic is extremely important when applying currents of this strength, in order to avoid dangerous shocks or burns. The electrodes must be large, and of such a nature that the current will be uniformly distributed over all points of contact. An ordinary sponge electrode often has one or more places where the metal is almost directly in contact with the skin, and consequently practically the entire current would pass to the skin at a small spot and produce a burn. The active positive electrode is made of sheet metal fitted to the shape of the side of the face, and with three prolongations extending over the forehead, the upper jaw, and the lower jaw. Felt, clay, or kaolin wet with solution of sodium bicarbonate prevents any metallic contact with the skin. The indifferent, negative electrode is of the same nature, and is applied at the nape of the neck or between the shoulder-blades. A rheostat should be used to turn the current on and off extremely gradually.

A continuous current of as much as 60 ma. will sometimes succeed in greatly relieving a case of trigeminal neuralgia after extraction of teeth, nerve resection, and removal of the Gasserian ganglion have failed—and the improvement may be permanent.

The Method of Mild Galvanization.—Three to twelve milliamperes may be applied for an hour at a time from similar electrodes.

Distribution of the Current in Applications to the Face.—The heavy galvanic currents which are sometimes applied for facial neuralgia,

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[1] Archive de Electricité Medicale, 1904.

either for the effect of the currents themselves or that of the medicinal ions carried by the current, do not pass in a straight line from the active electrode to the nape of the neck, where the indifferent electrode is placed. The current is diffused through every part of the head and neck, but is of greatest density along paths of least resistance. It passes with a practically uniform density through all parts of the skin in contact with the electrode, and also through muscles and fascia. When it comes to bone, it encounters resistance which is very much greater than at the different foramina and the vessels and nerves passing through them. The greater part of the current, therefore, follows these important structures and passes through the Gasserian and other ganglia and the brain, cerebellum, and medulla.

The symptoms observed by Gautrelet (p. 392) from the application of similar currents in rabbits are due to a primary stimulation and an ultimate paralysis of the nervous system along these conducting paths.

The method of heavy currents for long applications is to be applied with great caution, and only by an expert physician. The following physiologic effects are introduced at this point to enforce this admonition.

Although the electric treatment of trigeminal neuralgia is of great service, particularly in the milder cases, it cannot be said that at the present time any sure electric method is known for the very severe cases, and one must sometimes have recourse to surgical procedures which have been advised. Alcohol injections into the substance of the Gasserian ganglion or the affected branch of the nerve have proved to be the simplest and most efficacious method of treating these affections. Such injections are easy of application, are not attended by any disastrous by-effects, and the experience of Schlosser, Levy, and others shows that relief may be given for years at least, even if such injections do not make a permanent cure.

Treatment of Trigeminal Neuralgia by x-Ray and by High-frequency Currents.—These important and often successful methods are described on pp. 573 and 1084.

Radium.—This has also been used, but without lasting success, in the cases which the author has seen.

Cervicobrachial Neuralgia.—Neuralgia in one or more of the branches of the brachial plexus is not infrequent. The pain is usually felt in the neck, and shoots down the nerve-trunks to the arm and forearm. Movements of the arm are usually very painful, and the hunched-up shoulder and half-carried arm are characteristic of the attitude of these patients. The most frequent causes of brachial neuralgias are exposure to cold or injury, tumors, and poisoning from gout, alcohol, lead, or syphilis.

Brachial neuritis may be an expression of a greater degree of injury in the nerves at their origin in the plexus, or somewhere in their course. Here the pain is apt to be more severe, the nerve-trunks themselves become tender, and trophic changes take place in the muscles, the skin, and the nails.

The deltoid muscle, for reasons as yet little appreciated, is apt to develop a deltoid neuralgia or neuritis. It is, as a rule, a mild inflammation of the circumflex nerve. It is a not infrequently annoying trouble among people who write considerably, and may perhaps be classed at times as an occupation neurosis. It is a not infrequent disorder among workers with the broom, and is seen here in some of its more severe forms.

In the diagnosis of the site involved in cervicobrachial neuralgia and neuritis certain additional symptoms are of value. In inflammations low down in the cervical area, involving the first dorsal, pain over the clavicle is very marked. Furthermore, a neuritis in this region is apt to involve the sympathetic fibers, which have a relation here with the upper dorsal segments of the cord. The evidences of these sympathetic signs are a slight retraction of the eyeball; the lids come closer together on the affected side, the outer angle droops, and there is a slight contraction of the pupil on the affected side, with diminished light contractility. Some cases show a dilated pupil on the affected side.

Many of the severe cases of brachial neuritis are extremely obstinate, persisting at times for months rather than weeks, and they tax the therapeutic resources of the attending physician.

In addition to ordinary methods of treatment by rest, salicylates, iron, heat, and general supporting measures, counterirritation by means of the actual cautery and the use of electricity are the two most satisfactory measures to employ.

Electric currents are harmful in the very early stages of the affection, and practically the only forms that are of service are the direct, high-frequency, and sinusoidal currents. Induction currents are usually harmful. Exercise, at least so long as pain is present, is very prejudicial.

A mild galvanic current, not over 5 or 6 milliamperes, should be applied. The positive pole is to be applied over the painful nerve-trunks; the negative pole, to the back of the neck. The currents should not be interrupted, but should pass continuously over the affected nerve-trunks for at least ten minutes. The pole should be shifted from time to time, but not removed from contact with the arm.

The sinusoidal arm bath is of value when the pain has receded to such a degree that the pain is felt only on movement. High-frequency currents are often beneficial in the treatment of the chronic painful stages of the disease. They relieve pain greatly, even when they exert no marked effect upon the course of the neuritis.

Intercostal Neuralgia.—Bergonié's method of covering the painful area with a large positive electrode and applying currents of 50 to 80 ma. for half an hour at a time is effective here. The same careful technic is essential as in cases of trigeminal neuralgia. The *x*-ray is very effective in these cases. Glass vacuum electrodes from the Oudin monopolar resonator also succeed very well. A local electric-light bath is excellent, producing its effect chiefly by dry heat, and if the skin is slightly blistered, this does not cause pain.

Sciatica.—This is perhaps the most frequent of all the neuralgias of the body. Lying, as it does, in an exposed position, the sciatic nerve is subjected to frequent stretching, and not infrequent chilling and trauma. It is a medley, in reality, of conditions rather than one, and what has been written with reference to the occurrence of referred pains must be borne in mind in all cases in which pain in the sciatic nerve distribution is found.

As a referred pain, sciatic neuralgia is frequently found as a result of affections of the prostate gland, of hemorrhoids, of fissure of the anus, and in a few visceral conditions in women associated with retrodisplacements and procidentia. These are not cases of true sciatic involvement, although the severity of the pains may lead to such a diagnosis. In much the same way chronic hip-joint affections may give rise to sciatic pains.

Pressure on the nerve from chronic constipation, from a pregnant uterus, and from tumors is to be borne in mind. Chronic progressively increasing pain in the sciatic distribution points to a tumor pressing upon the nerve-trunk within the pelvis.

Finally, one has to bear in mind that specific herpetic eruptions occurring in sciatica point to inflammation in the sensory ganglion. These cases are frequently severe, but are apt to recover with a fair degree of rapidity.

The symptoms will vary much. The referred pain sciaticas are not of very wide distribution as a rule; those due to herpes may involve most of the branches. The true perineuritic sciaticas vary considerably, sometimes involving only a few branches, at other times occupying most of the entire distribution. The agonizing and paroxysmal nature of the pain is one of its chief characteristics. It is usually increased by movement of any kind, and more particularly so by all those movements which call for hyperextension of the nerve. Tenderness along the nerve-trunk is usually present. It is apt to be absent in the referred pain sciaticas. As a rule, the pains are worse at night, and eventually the patient is forced to limp and hold the limb stiff, frequently giving rise to a distinct and typic posture, with a resulting deformity.

So far as electric treatment of sciatica is involved, it should be considered purely as an adjuvant, although high-frequency current applications and those of Leduc's low-tension interrupted current are often of immediate and permanent relief in a number of the most intractable cases.

In the referred pain sciaticas counterirritation by the faradic brush or the static breeze is of signal service, but is useless in the severe perineuritic cases.

Heavy constant currents are valuable for their sedative effects. Large electrodes should be used, and long applications are necessary—30 to 60 ma. for from ten to twenty minutes—one electrode over the iliac fossa, the other to the sciatic nerve in some part of its course. Both ascending and descending currents should be tried, since the determination of the best direction of the current has been, and is still, the subject of considerable controversy. In both acute and long-standing cases high-frequency currents are of very great service. They seem to have most value in cases in which thickened painful nerve-trunks are present. Just why, is not known. It is highly injurious to attempt to treat sciaticas of the perineuritic type too early. Absolute rest is the first requirement if one would avoid the chronic infiltration connective-tissue changes which inevitably lead to the more protracted chronic forms of the disease. Even the use of the constant current, which is the only admissible form, should not be begun prematurely.

Various forms of the sinusoidal current are useful in the subacute stages. The bipolar bath with this type of current is most satisfactory. It should be used only when relief follows its application. If such usage provokes pain, it is wiser to delay its application.

In the very obstinate forms it may be assumed that adhesions have been formed. These may frequently be diminished by the use of high-frequency currents and ultraviolet ray emanations. The results in some of the author's cases (p. 573) have been magic.

Chronic Sciatic Neuralgia.—*Galvanic, Faradic, and Static Applications.*—*Weak Galvanic Currents.*—Eight or ten milliamperes may be applied, as already described for heavy currents; or *Benedikt's method of galvanization* of the *sacral plexus* by a metallic electrode in the rectum and a large electrode over the sacral or lumbar regions; an electric lavage may be used instead of the metallic electrode for the rectal pole. *Faradization* may be applied by sponge electrodes, one over the lumbar region and the other over different painful spots and the affected muscles; or the active electrode may be a faradic brush, and, if so, the secondary coil should be of fine wire, to avoid muscular contractions. *Static insulation* followed by *static sparks* along the spine and the sciatic nerve, and *static induced currents* are all useful.

Static Induced Currents for Sciatica.—The patient is not insulated, and holds a large plate electrode connected with the external armature of the positive Leyden jar upon the skin of the epigastric region. A small metallic ball electrode from the external armature of the other Leyden jar has an insulated handle by means of which it is applied to the skin in the lumbar region over the emergence of the sciatic nerve from the vertebral canal, and then to the different painful spots without breaking contact with the skin. The discharging rods of the static machine should be separated far enough to produce visible contraction of the lumbar muscles at each spark. This separation will usually be less than half an inch. After ten minutes' use of the negative electrode the connections may be changed so as to make the positive electrode the active one. A static bath with powerful sparks along the lower part of the spine and the sciatic nerve may be given at another treatment, alternating with the static induced current treatment. The best results are obtained from daily treatments, and De Blois[1] reports 80 cures out of about 100 cases treated.

General Measures for Sciatic Neuralgia.—A great many cases require some general treatment, dietetic or medicinal, and by static baths or hydro-electric baths with sinusoidal currents, without which the local electric treatment may fail.

The Method of Galvanization for Acute Cases of Sciatic Neuralgia.[2]—This is applicable from the very first moment of the attack, but does not succeed so well after the case has become chronic. An electrode, preferably the positive, but this is not essential, 6 by 7 inches in size, is placed over the upper part of the sciatic nerve, a convenient way being for the patient to sit upon this electrode. The other electrode is a large one, bent so as to fit around the calf of the leg; or the other electrode may be formed by a foot-bath extending up to the ankle. A certain amount of glycerin added to the water will prevent a burn occurring at the upper surface of the water. Wearing a stocking also acts as a preventive. The current strength is to be from 30 to 50 ma., and is to be applied for half an hour to an hour—at first, every day.

The prognosis may be judged of by the results of the first few treatments. If this treatment has been begun a few days after the outset of the attack, and no marked relief is obtained in seven treatments, the case is probably dependent upon a constitutional cause, and it will take several weeks to effect a cure. If relief is prompt, the case will be cured sooner.

Galvanic Currents for Sciatic Neuritis.—There is the same arrange-

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[1] La Presse medicale, April 19, 1905.

[2] Albert Weill, Jour. de Physiotherapie, August, 1903.

ment of electrodes, but the application is much weaker and shorter—only 8 or 10 ma. for about ten minutes. The positive electrode may be a roller electrode passed over the different muscles which are painful or show trophic changes.

Of recent years it has been suggested to use certain remedies which are thought to have an effect in diminishing the proliferation of connective tissues. Such a remedy as potassium iodid has been used for years, and with a certain amount of success, but its range of usefulness is very narrow. More recently thiosinamin and fibrolysin have been recommended in the treatment of conditions accompanied by proliferation of new connective tissue. The former has a very limited range of application, but the latter may be tried in some of the chronic cases accompanied by thickening of the nerve-trunks when other remedies have ceased to be of service. Massage in combination with electricity is frequently of value, but should never be used in the acute or subacute stages, that is, when the nerve-trunks are tender. Just what electrolytic ionization may do for the perineuritic sciaticas is an open question.

Surgical procedures, such as stretching the nerve, are hazardous, but dissection and actual division of definite adhesions which may be found and longitudinal splitting of the nerve has been practised to advantage.

Treatment of Lumbago by Faradization.—Sponge electrodes 2 inches in diameter are applied, one on the vertebræ and the other shifted from one painful spot to another. The fine wire coil with very rapid vibrations is used, and the strength is increased as toleration is established. Mechanic vibration of the affected muscles finishes the treatment, which takes ten minutes and may be repeated once or twice a day.

Electricity in Renal Pain.—It often happens that a patient who is sent for *x*-ray examination for calculi, and in whom none is found, will be very much benefited by the *x*-ray exposure.

Galvanofaradic currents as strong as the patient can bear may be applied from two electrodes about 4 inches in diameter, placed one in front and one behind the painful kidney.

Neuralgia of the Testis.—This is treated by positive galvanization with as strong a current as can be borne. The testicle is wrapped in moist cotton, outside of which is lead-foil connected with the conducting cord. The negative electrode should measure 4 by 5 inches, and is applied to the lumbar region.

ELECTRICITY IN TREATMENT OF ORGANIC DISEASES OF THE CENTRAL NERVOUS SYSTEM

SPINAL CORD

The chief diseases of the spinal cord may be grouped as those due to—

(1) Disease of the motor ganglia—poliomyelitis type.
(2) Disease of the motor paths—lateral sclerosis type.
(3) Disease of the sensory paths—tabes dorsalis types.
(4) Diffuse disease—myelitis type.
(5) Intraspinal disease—syringomyelic type.

Diseases of Motor Ganglia.—*Poliomyelitis; bulbar palsies* in higher distributions; *chronic atrophies* (*Poliomyelitis chronica*), mixed types; *amyotrophic lateral sclerosis.* The chief diagnostic features of the poliomyelitis syndrome are loss of tendon reflexes, muscular atrophy, trophic disturbances, no sensory phenomena, reaction of degeneration. Grave forms of neuritis often may be confused with poliomyelitis, but the pain element in the former affection usually suffices to make a differential diagnosis.

Acute Poliomyelitis—Infantile Spinal Palsy.—There is abundant evidence tending to show that this, of all the affections of the nervous system, responds with marked advantage to the use of electricity. There is almost no time following an attack of poliomyelitis after the very acute symptoms have passed when electric treatment may not be of service. The ancient dictum that if reaction of degeneration has been present for at least three months regeneration may not be looked for is totally false, and considerable degrees of recoverability may obtain after more than two or three years of absolute loss of electric excitability.

It is becoming more and more apparent that the involvement of the ganglion-cells in poliomyelitis is extremely irregular, and there is abundant evidence tending to show that rarely are all the cells in the nuclei supplying the muscles equally affected. Thus, notwithstanding very severe and deep implication of a muscle group, many of its fibers are spared, and the ganglion-cells are capable of stimulation, with retardation of further degeneration in the muscular fibers. This appreciation that functional muscle-fibers are often retained for a long time in infantile paralysis was first pointed out by Duchenne, of Boulogne, and it is very easy to neglect this point of view in the study and treatment of these cases. Special efforts should, therefore, be directed to the cultivation of these residual sound fibers, in order that they may themselves retain what capacity they have, which, without proper physiologic stimulus, would inevitably be lost.

The more extensive the nucleus of origin of any group affected may be, the more certain it is that sound fibers and unaffected cells will be found. It is, therefore, of great importance in making the diagnosis of any given case, so far as electric results are to be obtained, to bear this definite fact in mind. Reference to the cell groups in the cord (see p. 449) may be made to determine this point.

In general it may be said that the grades of injury in acute poliomyelitis are at least threefold. Certain muscles show great weakness, but are not completely paralyzed; reaction of degeneration varies within the limits of the muscles, but it is not absolute all over; trophic changes are not present to any marked degree, and there are few evidences of temperature changes in the affected member. These are the muscle groups for which mild exercise, passive movements, and massage result in ultimate recovery, but there is no doubt that electric stimulation, if not begun too soon, at least not for eight to ten weeks after the onset of the paralysis, will hasten the recovery very distinctly. Even after years of neglect such muscles may be helped by proper electric stimulation, particularly in those cases in which the reaction of degeneration is not marked or is absent. Cases are certainly on record of some ten to fifteen years' standing in which improvement has followed the electric treatment.

As for those patients in whom complete reaction of degeneration is found, less can be done by electricity. They are not hopeless, however, by any means, and a marked return of power may be found in muscles which, for a long time, have shown very typic reaction of degeneration, even when it has extended over a considerable period of time—even as much as five or ten years.

In the treatment of these cases of poliomyelitis care should be taken not to commence electric, and mechanic treatment as well, too early. While the ganglion-cells are acutely inflamed it is harmful to excite them electrically, and only after these little patients have been at rest for a period of from eight to twelve weeks should the more active use of electricity and forced movements be begun. In some cases where contractures have a tendency to come on early, proper orthopedic procedures and the stimulation of antagonistic muscles may be advisable.

The early electric treatment should not be begun so long as there is any tenderness in the muscles or in the nerve-trunks. The presence of pain in these patients should not be overlooked. In the early stages it argues for a meningeal involvement.

After careful tests are made and the results recorded, each muscle being tested systematically as to its motor point and its muscle substance and tendon reaction, treatment should be directed toward stimulating the unusable muscles. The galvanic and faradic battery currents are those mostly employed. In the cases in which change of temperature and trophic disturbances have been observed the early signs of repair are noted in the gradual modification of these symptoms to conditions more nearly approaching the normal. The circulation improves, the limbs commence to fill out, the blueness becomes less marked, and the temperature rises.

Electric treatment may be carried out in a bath or by ordinary electrodes, and should be aided by manipulative movements, light massage, and passive resistance movements.

Later, electric reactions commence to appear as the few non-diseased fibers commence to take on normal functions. The first reactions are usually those in response to the induction-coil.

The static wave current has been applied for a profound local effect in infantile paralysis. Electrode of 22-gauge soft metal, 11 by 8 inches, to upper half and lower two-thirds of spine alternately for twenty minutes with 8 or 10-inch spark-gap from 8-plate static machine.[1]

Exercising Paralyzed Muscles by Static Induced Current.—The large indifferent electrode, 10 by 14 inches, is moistened and applied to the back. Smaller ones are strapped to several different affected muscles and all connected. Connections are made with the outer coats of the two Leyden jars. Slow speed is turned, and a spark-gap that will yield marked but not painful contractions (140 per minute) for about ten minutes.

Light, mechanical vibration, and massage are also used.

Jones' summary represents the author's position so thoroughly that we cannot refrain from quoting it in this place:

"In every case of infantile paralysis which is not clearing up satisfactorily it is important to apply electric treatment, continuing it for six months to a year or more.

"It is the exception for a muscle to be so completely destroyed by poliomyelitis as to be without any functional fibers, and these remaining fibers can be cultivated by persevering stimulation of them.

"Where the muscles show only the reaction of degeneration, or even where reactions are entirely abolished, some improvement may be hoped for in a good percentage of cases.

"The amount of restoration which may be possible in a muscle will

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[1] W. B. Snow, Jour. Advanced Therap., October, 1912.

depend upon the number of surviving ganglion-cells. With prolonged treatment recovery advances very much farther than one might expect, and is infinitely superior to the results obtained when treatment has not been given.

"Even where the electric reactions are not altered in quality, it is not good practice to leave the case to take care of itself."

Chronic Poliomyelitis—Progressive Muscular Atrophy.—This is a large group of cases of varying causation, pathologic change, and outlook. It is difficult to treat them all as one disorder. Two general types are to be differentiated—the neuritic and the central. Irregular reactions to electric currents are found in both. In the ultimate stages of complete atrophy absolute loss of electric response is the rule.

The results of electric treatment in these atrophies are not to be viewed in an oversanguine light. There is no doubt that conscientious and consecutive treatment will retard the progress of the atrophy.

In the central or spinal types this effort is rewarded with more success than in the neuritic or myopathic forms. Erb has recommended the direct application of the galvanic current to the spinal cord, laying particular stress on direct electrization of those segments of the cord in which the major implications are to be found—usually the cervical or lumbar enlargements. Jones recommends the use of the induction-coil currents in mild doses in these cases.

Progressive Muscular Atrophy.—Hydro-electric baths with triple-phase currents cured a case reported by Albert-Weil.

As to the use of other forms of electric stimulation in the chronic atrophies, experience is not yet cumulative enough to enable one to come to definite conclusions. High-frequency currents have been used by a number of observers, among whom Denoyés has reported good results, but one is compelled to withhold conclusions in the cases reported up to the present time.

Disease of Motor Paths (*Lateral Sclerosis Type*).—On general principles it may be said that disorders of the pyramidal tracts are not only not helped by electric treatment, but, on the contrary, are harmed. Up to the present time there are no reports of help coming to these cases. In those cases in which pressure on the lateral tracts by tumor causes the affection, *x*-ray treatment occasionally diminishes the size of the tumor, but its use is not advisable unless surgical intervention is absolutely impossible.

In *multiple sclerosis* no definite progress has been made. Certain cures have been reported, but these were undoubtedly cases of hysteria. It is well known that multiple sclerosis has periods during which improvement takes place, only to have the patient slip further back at the next advance. Psychotherapy also has a marked value in helping patients with multiple sclerosis to make less of their ills than is their usual wont.

Certain advances ought to be made in the electric treatment of multiple sclerosis patients. The tissue proliferation is of a type which, by analogy, should be affected by high-frequency currents, just as we know that the perineuritic inflammatory exudates of chronic character are modified. The field is not hopeless by any means.

Disease of Sensory Paths (*Tabes Dorsalis Type*).—The evidence bearing upon the availability of electricity for the treatment of disorders of this group is far from being conclusive. Much depends upon the attitude of the observer. It is admitted that the cure of true posterior sclerosis has not been advanced at all by any yet devised form of electrically induced energy. Pains may be relieved, minor palsies helped, the tonus of weak muscles improved, and the functions of the bladder and rectum much stimulated, but true tabes dorsalis has not yet succumbed, nor can it yet be seen why there is any likelihood of its doing so. Pseudotabes of neuritic nature following poisoning by alcohol, lead, aspergillus, ergot and its allies, or other agents causing a mild ascending degeneration may recover after the application of the electric treatment, but it is not even certain in these cases that the neuritic process has been hastened in its repair by the electricity. These pseudotabes cases recover after treatment by almost anything, or nothing, and hence it is of little profit to argue the question without a *raison d'être.*

Application of Galvanic Currents to the Spine in Locomotor Ataxia by Means of Cell-baths.—The patient may be seated in a perineal bath, which forms the positive electrode, while both forearms rest in baths which are connected with the negative pole. A galvanic current of 25 to 30 ma. is gradually allowed to flow for about ten minutes. The treatments are given three times a week for four to six weeks. All the current passes through the patient's body, and according to the rule by which currents travel chiefly by the best conducting path, we know that a large proportion of it traverses the spinal cord. Allard and Cauvy,[1] who suggested the above technic, believe that a favorable effect may be exerted upon the hyperemia and the sclerosis, and especially the lightning pains and the transitory paralysis of the early stages of the disease may be benefited.

Vesical Crises in Locomotor Ataxia. Treatment by Galvanic Currents.—The bladder is filled with boric acid solution, and a negative urethral electrode is introduced into the bladder. A large positive electrode is applied over the lumbar region, and a current of 40 ma. is gradually turned on and allowed to flow for fifteen minutes. Treatments are given twice a week.

Can it be claimed that electric treatment will delay the progress of a tabes case? In view of the great chronicity of the affection and its irregular course, particularly its long periods of non-progression, it is hazardous even to claim this for electric treatment in this disease.

The last word, however, has not yet been spoken, and it will be premature to negative on á priori grounds some new claimant to therapeutic honors. It is certain that the radium treatment, *x*-ray treatment, Finsen-light treatment have thus far disappointed their advocates.

The requisites for proving the claims are extremely severe, in view of the many-sided character of this affection.

The x-Ray and High-frequency Currents Applied to the Spine in Locomotor Ataxia.—The author has seen great lasting improvement, though not a cure, in a case which was also treated by mercurial injections.

Diffuse Spinal Disease (*Myelitis Types*).—In those patients in whom the paraplegia is spastic we cannot look for much relief from electric treatment, but in the ataxic types associated with lost knee-

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[1] Rev. Internat. de med. et de chir., April 10, 1906.

jerks, in which involvement of the gray matter seems evident, the indications for electric therapy are somewhat similar to that already considered in the Progressive Muscular Atrophies. Certain of the ataxic paraplegias are much benefited by the judicious and persistent use of both galvanic and faradic currents.

Intraspinal Disorders (*Syringomyelia Type*).—It is a curious fact that of all the disorders of the spinal cord which would seem to offer the least hope for benefit from electric treatment, syringomyelia should be one in which such treatment has been followed by definite and unmistakable signs of betterment. Raymond has reported the good effects of x-ray treatment in a number of cases. The pains have been stopped, the progress of the atrophies delayed, and other signs of improvement indicated a regression in the tissue proliferation in the syringomyelia area. Experiences of this are, up to the present time, too fragmentary to permit of wider generalization, but the results in the cases reported have been striking. This, taken into consideration with the well-known conservatism of the reporters, should be sufficient to encourage further investigations along this line.

BRAIN

The most important organic brain affections here to be considered are brain tumors and brain hemorrhages, resulting in the hemiplegic and diplegic syndromes. The most striking of these are the infantile cerebral palsies and the adult hemiplegias.

A definite decision concerning the utility of electricity in organic affections of the brain cannot yet be reached. Although various observers have been using all types of currents for years, and some are extremely enthusiastic as to what electricity can do in this class of affections, the more conservative and careful observers approach the matter with considerable reserve. Extravagant claims would border on charlatanism, but it were equally as false to common sense to say that what we now know is of no service, and even to maintain that all that may be learned is bound to be futile.

But not to deal in futures, it is sufficient to make the general confession of faith that our present standpoint is that electricity may be an extremely important adjunct to our therapeutic resources, if not the entire source of reliance.

Hemiplegia.—In the organic hemiplegias it should be borne in mind that the first motor neuron is involved. We cannot expect by electric or other means to obtain the regeneration of the fibers in the affected corticospinal path. The injury done here is more or less inevitable and unmodifiable. The spinal peripheral motor path, however, is unaffected, and the changes which take place in the muscles, bones, and blood-vessels of the paralyzed limb are the result not of any real inherent affection in their own proximal neurons, but of the lack of physiologic functioning in the corticospinal part of the path.

It is, therefore, evident that persistent regard paid to the unmodified peripheral motor tract is absolutely essential, and one finds in the use of electric currents a very helpful therapeutic resource. Old hemiplegic cases lacking electric treatment or treatment by massage become more and more helpless, but by means of intelligent muscular gymnastics, with the aid of galvanic and faradic currents, a great amount of improvement may be brought about. This improvement, however, will not pass beyond a certain point, and just how far such treatment may be effectual depends upon the individual case: general laws cannot be postulated.

For the prevention of the development of rigidity the use of both the faradic and galvanic currents is beneficial. After rigidity has set in and has been present for a number of years the results are less valuable—in fact, massage is then more serviceable.

Treatment of Hemiplegia.—Begin passive movements of every articulation from the very day of the stroke. This will prevent arthritis, the deformed attitudes, pain, and, in a great measure, the muscular contractures which make the sequelæ of an apoplectic stroke so much worse than would be the case if the condition were simply that of paralysis of certain muscles. Reëducation of voluntary motion is to be begun as early as possible. Electricity may be useful in the treatment of atrophy of certain groups of paralyzed muscles, but not for general application to the whole hemiplegic side of the body.

The electric treatment of hemiplegic cases should be begun only after the acute symptoms of the paralysis have fully developed—that is, in from four to six weeks after the initial lesion. As pain is rarely an accompanying symptom of hemiplegia, this does not have to constitute a complication. The improvement in the hemiplegic cases usually comes on more or less rapidly—in some cases almost immediately. The galvanic currents are best applied, the direction being that of the course of the motor tract, namely, from the spine outward. The anode is placed along the spine, and the cathode at the periphery, the anode being moved slowly up and down without being raised from the skin. The electrode should be of medium size, and the duration of the application should be from ten to twenty minutes, and should be made at least three times a week—preferably daily.

There are those who maintain that a certain amount of stimulation of the brain itself may be brought about by the use of the more carefully graded currents of Leduc. In the treatment of aphasia a certain amount of success has been claimed by certain French investigators. The application should be made by the alternating current of low intensity and slow interruptions, and should not be of more than five minutes' duration at one time, while care should be taken in ascertaining the resistance of the brain tissues to the interrupted current. This subject will be discussed more fully in a separate paragraph, under the caption of Electric Sleep.

Infantile Cerebral Palsy.—The individual lesion which may be present in this type of affection varies so widely that we cannot in this place attempt to outline the symptomatology of the group. Suffice it to say that the chief damage is done to the corticospinal neuron, and may manifest itself in monoplegia, hemiplegia, or diplegia. In the monoplegic types nature herself does much to minimize the damage done, and great improvement in the functional capacity of the affected muscles may be looked for from her unaided efforts. Both massage and electricity should be utilized early in the treatment of these paralyzed children. The indications are precisely the same as those which have been already spoken of in the paragraph on Hemiplegia.

It is to be borne in mind that the lesions in infantile cerebral palsy, when not due to a generalized encephalitis, are of the hemorrhagic type, and that functional losses are much more extensive than the primary anatomic defect. It should, therefore, be the aim of the electric therapeutist to minimize, so far as possible, the tendency to the continuance of this functional defect until the time when the exercising of the hemorrhagic area would of itself bring about an improvement in the condition as to movement. Both galvanic and faradic currents will prove of service, these currents being useful for the maintenance of nutrition. The use of massage in conjunction with the electric current should not be lost sight of, the two mutually assisting. Some students have obtained a like stimulation of muscular tone, and nutrition by the use of high-frequency currents, induction discharges, and static breezes. The latter, however, are more useful in maintaining skin nutrition than they are in affecting the muscular tissues beneath.

New Growths in the Brain.—Here the symptomatology is so varied that we must refer the reader to works on neurology. What can be expected of electricity in the treatment of new growths? It must be confessed that it is not by any means clear that the electric treatment of new growths is of much service, and this is not the place to consider what radium emanations or ultraviolet rays may do for certain forms of intracranial growth. In view of certain recent results obtained in the treatment of syringomyelia by the use of *x*-ray and by ultraviolet light, it cannot, on *á priori* grounds, be stated that similar types of tissue degeneration in the brain may not be beneficially treated with this form of electrically produced energy.

Manifestly surgical procedures are those best adapted for the treatment of intracranial growths, but in view of the gloomy outlook, even under the best of conditions, research in the matter of the treatment of growths by different types of electric energy should not falter.

Epilepsy.—It seems unnecessary to repeat that epilepsy is not the name of one disease—there are several different epilepsies. That the motor discharge induces the familiar picture is true, but the causes of the motor discharge vary from slight emotional excitement to actual anatomic destruction. It seems incredible that electric action could affect anatomically altered brain tissue to such a degree that the epileptic discharge could be modified, and such is the general experience of those who have tried electric methods in the treatment of epilepsy. Good observers, such as Althaus and Erb, have, however, reported beneficial results in certain cases of epilepsy. Erb particularly advises the use of the constant current in certain cases, the anode being placed first on the side of the forehead, with the cathode at the nape of the neck, and a weak constant current being passed for one minute. He later changes the electrode, the anode occupying the middle line of the head in front, the cathode being placed over the occiput, and the same type of current being passed for the same length of time.

X-ray treatments have been reported to have been of benefit in some cases, and it is conceivable that such treatment has had an effect upon a new growth which had been the primary cause of the irritation in the cortex leading to the motor discharge. One cannot, however, pin one's faith to these measures. They should be adopted as expedients only, and we are not yet in a position to maintain that they should be used primarily.

GENERAL NERVOUS DISORDERS

Of the more general nervous disorders, irregular forms of muscular spasm may be considered. So far as habit spasms and tics of various types, including the tic of torticollis or wry neck, are concerned, it seems certain that electricity is of very secondary value. In most of the habit spasms the psychic element is very strong, and electricity, instead of being of service, usually tends to aggravate the ills that are already there. Those forms of spasm or tremor or irregular tonic or clonic movements which are of an organic nature due to minute alterations in the vascular supply of the central nervous organs, also resist electric treatment.

So far as the cases of wry neck and of forced irregular posture, which are due to exposure to cold and muscular or neuromuscular involvement are concerned, electric treatment is par excellence favorable. Here the faradic current, or more particularly the static breeze, or induction-coil sparks are of great service.

Chorea.—Treatment of chorea by electric energy remains a terra incognita in neurology. Certain cases of chorea are undoubtedly much benefited by electricity, especially by the static breeze, or application of induction sparks to the spinal cord, or galvanic baths; but the action is probably due entirely to the tonic effects on the body.

Cases of chorea treated at St. Bartholomew's Clinic have been quickly cured by the application of glass vacuum electrodes from the Oudin resonator along the spine and over the upper and lower limbs.

If it be assumed that most choreas are, after all, the results of a post-infectious toxemia having a special predilection for the motor area, causing excessive irritability, or bringing about insufficient inhibition, then it is comprehensible why general electric stimulation by the static currents is as efficacious as it is at times. Furthermore, in the treatment of exhaustion states following excessive choreic movements electricity is of inestimable value and should be added as an adjunct in the treatment of this affection by the ordinary tonic measures usually carried out. Pharmacopeal therapy, hydrotherapy, and electric therapy combined give better results than any one alone. Jones has found in the treatment of these cases that the application of the negative breeze to the spine is a convenient and more agreeable method of treatment than the ordinary static spark procedure.

Occupation Neuroses.—These, as has already been said, are properly considered in the light of a complex etiology. They are cases of neurasthenia mixed with a bad psychic habit, and experience shows that in their treatment they are extremely obstinate. As is well known, such forms of occupation neuroses associated with cramp-like conditions in the muscles are common accompaniments to piano playing, violin playing, tennis playing, and tailors, shoemakers, and writers are often afflicted with it. A vast number of neuroses belong to this group.

Electric treatment is of service undoubtedly in the toning up of the muscles themselves, but it is more than doubtful whether it ever reaches the psychic factor in the disorder. Our own experience has been very disheartening in the electric treatment of these occupation neuroses, especially writer's cramp.

Galvanic Currents for Writer's Cramp.—A large negative electrode is placed between the shoulder-blades and the forearm rests in a bath of tepid water in which the positive electrode is placed. A current of 30 ma. is applied for fifteen or twenty minutes every day.

Exophthalmic Goiter.—Until the exact pathology of this disorder is placed upon a more rational foundation it were futile to claim for it that it may be cured by electric measures of treatment. There are numbers of cases in which electric applications of the induction current applied to the sides of the neck have proved to be of considerable service. These are probably those cases in which the goiter is largely due to disturbances in the functions of the cervical sympathetic nerves, and the electric treatment serves to restore in part at least a function which has been greatly altered by the toxemia of the overacting thyroids or parathyroids. Applications to the glands themselves have been made with a view to diminishing the amount of glandular substance secreted and thrown into the circulation. Whether electrolysis can bring this about, as has been claimed by a number of observers, is highly doubtful. At any rate, the question must remain an open one until more is known of this disorder. When it is recalled that Dubois, of Berne, reports the cure of a number of cases by the use of psychotherapeutic principles, it is necessary to realize the psychic element in producing the anxiety, tachycardia, and irritation phenomena in the disorder.

The electrodes may be placed at the sides of the neck behind the angles of the jaw with the negative electrode upon the side of the most marked exophthalmos; or the negative electrode may be placed at the nucha and the anode first over one carotid region and then over the other.

Another successful way to use the galvanic current in this condition is to apply an electrode to each side of the gland. The electrodes should be thoroughly wet in a solution of bicarbonate of soda and the current should be applied for fifteen minutes at a time, using from 10 to 15 milliamperes. The treatment can be applied twice a week. The direct application of a spark from a static machine has also been of great service, but, of course, it is rather a disagreeable method of treatment. When this is used the patient is placed on the insulated platform in the usual manner and connected with the positive pole of the static machine. The negative side of the machine is grounded; the patient holds what is known as a spark director (Fig. 320) in contact with the gland; the brass ball electrode, which is held in the hand of the operator, is brought

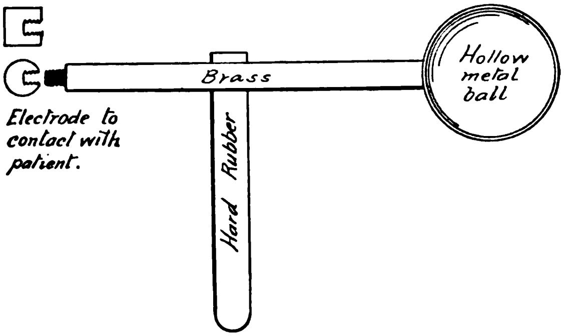

Fig. 320.—Spark director.

within 4 or 5 inches of the other end of the spark director, when a spark will jump. This is rather a severe treatment, but some cases have been greatly benefited by it.

Treatment by the x-ray and high-frequency currents has resulted in a certain percentage of permanent cures in the author's cases.

Hysteria.—The attitude assumed on this question is a more or less radical one. It is highly important in the first place to distinguish between hysteria proper as a well-defined and carefully described psychoneurosis, and hysteric or hysteriform symptoms which may be the accompaniment of a vast number of organic affections, not only of the central nervous system but also the entire body.

A characteristic feature in true hysteria is a certain foundation in character which permits of the ready dissociation of the personality, and it is, therefore, characterized by great emotional instability and a childish development, stamping the individual at once as a being more primitive than the education and environment would seem to show; in other words, the true hysteric character is a primitive character, and it is well recognized that true hysteria is much more prevalent among primitive peoples, such, for instance, as the natives of Java, of whom Kraepelin has made a thorough study, the American negro, and other types. The hysteric character is never altered by electricity. Many manifestations of the dissociation in consciousness, such as the pains, paralysis, anesthesias, etc., are very frequently relieved by the use of electric currents, particularly those of a painful or shock-like nature. Those forms of energy are useful which make sudden unexpected demands upon the attention of the individual, and which for the time, to use Janet's phrase, are capable of rousing the nervous tension to such a point that the dissociated element in consciousness is brought back into the hierarchy of the conscious personality. With the cessation of the treatment, however, disaggregation takes place in another association, other symptoms arise, and the fundamental features of the personality remain untouched. In fact, the wonder-working, as it were, of the electric display only contributes to the receptivity of the individual to certain classes of impressions, which tend to perpetuate the primitive nature of the individual instead of affording any means of education. If the electric treatment is used only as a means to an end, an attempt, as it were, to first gain the attention of a very loosely aggregated personality, which is then worked upon by proper psychotherapeutic measures, then its use may be advisable, but as pure electricity it works to the disadvantage of the individual. The galvanic or faradic treatment of hysterically paralyzed limbs is, we believe, very harmful to the individual. The element of suggestion that the limb is paralyzed by the incessant working over it by electricity tends to perpetuate the paralysis and may make it permanent.

On the other hand, so far as the treatment of hysteric *symptoms*, which are the reflex of disorders of an entirely different nature is concerned, electricity is often of a great deal of value, and when it is of service the attention of the physician should immediately be awakened to the possibility of an underlying organic cause for the hysteric manifestations. Thus, the common association of hysteric symptoms with such disorders as tumors of the spine, tumors of the brain, abcesses of different portions of the body, tumors of the kidneys, tuberculosis, floating kidney, stone in the bladder, etc., etc., all of which conditions are known to give rise to hysteric symptoms very frequently, should not be overlooked, and when these are alleviated by electric treatment the physician should not be deluded into belief that they are hysteric and that the patient is well, but the very fact of their being amenable to electric treatment should point in the direction of a further search for the cause of the hysteric manifestations. Thus, it may be seen that the electric treatment of these conditions offers a very important diagnostic clue.

Mental Disorders.—It is entirely too early to generalize upon the value of electric forms of stimulation in mental diseases. If it be of service at all, it is of some assistance in the treatment of depressed states, usually the depressed phases of maniacal depressive insanity. Also, perhaps, in the mild or severe depressions associated with senile or presenile psychoses in which the element of arteriosclerosis is the primary pathologic factor. It has already been pointed out that certain forms of electric energy have shown themselves to be of service in the treatment of some cerebral tumors, and mental changes due to cerebral tumors are concomitantly helped thereby.

It is beyond question, however, that electric forms of energy have no radical effect on any definite psychotic conditions, but as an adjunct in the general treatment of some of the psychoses electricity is undeniably of a great deal of benefit. And in the large groups of cases of the psychoneuroses, particularly in the neurasthenic group in which the mental state closely approaches insanity, electric stimulation, particularly by various adaptations of the static current, is of general tonic value.

The exact limitations of electric stimulation of metabolism and the effects that such change in metabolic activity may have upon the development of psychoses are matters which are as yet in the realm of pure hypothesis. It is highly desirable that careful consecutive studies be made on definite forms of psychoses, so far as we believe that such definite forms do exist, in order that clearer notions of the value of this form of energy may be obtained.

NEURASTHENIA

The beneficial effects of electricity in this disease are of two different physical kinds besides that due to mental impression. Practically all forms of electricity which are suitable for use in this disease improve the general nutrition and digestion. The urine contains more urea and less uric acid and albumin and sugar if the latter are present. In cases of malnutrition with phosphaturia and azoturia electricity increases bodily weight and causes the urine to become normal. The effect, so far described, is one of regulation of cellular activity and of a beneficial effect upon the central nervous system.

The second kind of effect from electricity is upon the circulation, and this may be in the direction of causing an elevation or a reduction in blood-pressure according to the form of electricity which is employed. Generally speaking, extremely high-tension applications, like the static spark or breeze and the spark or effluve from the Oudin resonator (the latter giving a high-frequency high-tension current), increase the blood-pressure, and while called for in cases with hypotension, are contra-indicated in neurasthenia with high arterial tension or with arteriosclerosis. Comparatively low-tension high-frequency currents, like those from the d'Arsonval apparatus, have a marked effect in lowering arterial tension, and are especially indicated in neurasthenia with high arterial tension or with arteriosclerosis.

Application of Static Electricity in Neurasthenia.—It is not necessary that the static machine should be of the largest and most powerful type, but it must work well and give a good discharge between balls 3 inches or more apart.

Static Insulation or Static Bath.—The patient sits on an insulated platform with his feet resting upon a metal plate connected with the negative prime conductor, while the positive prime conductor is grounded. Treatments last for five minutes at first, but are increased to fifteen minutes, and are given every day. This is an excellent tonic to all the tissues in the body.

Static Breeze.—The patient is insulated as before with the negative pole, while an electrode from the positive terminal with one or several points is brought near some part of the surface of the body. The effect is a sedative one upon the central nervous system. For instance, the sensation as of an iron band around the head is relieved by a few minutes, application of the static breeze to the nape of the neck. A favorite application in neurasthenia is a static breeze from a crown suspended over the head and connected with the positive pole while the patient is negatively insulated. A reversal of this polarity causes a much greater prickling sensation in the scalp and makes it disagreeable.

The positive pole is readily distinguished by the fact that the discharge from it to the negative pole when they are an inch apart may be diverted by a piece of wood, such as a match. Moving a piece of wood over the surface of the positive pole, one is enabled to make the discharge start from wherever, within certain limits, the wood touches or even approaches the positive pole. *The positive discharge follows wood.*

Another way is by the fact that a brush discharge of a violet light several inches long may be obtained from a pointed electrode connected with the positive pole of the static machine, while no discharge is perceptible from a point connected with the negative pole until it is close enough to send a spark to the surface.

Insomnia from neurasthenia often yields to a static bath with a head breeze, and so do all kinds of nervous apprehension and even delusions; but excessive or too prolonged stimulation of muscular contraction by the static wave currents will cause insomnia.

Static Sparks.—The patient is in negative insulation, and a metal ball electrode connected with the positive pole is brought near enough to send a spark to the surface of the body. This may be applied through the clothes, and the ball electrode should be approached with a sort of quick, striking motion, permitting only one spark to pass before the electrode is again beyond sparking distance. A stream of sparks at one place is painful and exceedingly disagreeable.

For a general tonic effect and to raise the arterial tension a series of sparks along the spine are excellent.

They cause localized contraction of muscular fibers and are indicated in pronounced muscular atony, either general or local.

Static sparks applied in the left iliac region have a most beneficial effect upon the constipation which is often a symptom of neurasthenia, and they also restore the appetite and relieve the general sense of depression.

Indirect Static Sparks.—For all the purposes for which static sparks are applied, the effect may be obtained by grounding the positive pole of the static machine (connecting it with the water or gas or steam pipes), and applying the sparks from an electrode which is also grounded. This makes the application much easier for the operator, since the electrode is not charged and need not be insulated.

Static Friction or Massage.—The patient is in negative insulation, and the positive pole is connected with a roller electrode, which is rubbed over the surface of the body outside the clothes, or the same application may be made indirectly, grounding the positive pole and the roller electrode. The effect is that of a continuous shower of sparks, the length of which is determined by the thickness of the clothing. The application is a severe one and makes the strongest man twist and squirm. The electrode should be moved over the surface quickly and should not be applied for more than a few seconds at a time. Pron[1] has most admirably epitomized the indications for static, faradic, and galvanic applications in this disease. He considers static massage as useful in cases with anæsthesia en plaques and with spinal cord irritation, causing seminal emissions and cramps and exaggerated reflexes. The applications are made to the upper part of the body.

The Static-induced Current.—The pelvic neuralgia of neurasthenia in women is almost always relieved by vaginal applications of the static-induced current. Albert-Weill's[2] method of application is by a vaginal electrode connected with his rheostat for controlling the strength of the static-induced current. The operator holds the insulated handle of this electrode with one hand while he massages the abdomen with the other.

The application should be as strong as can be borne without discomfort.

The symptoms especially calling for treatment by static electricity are insomnia and myasthenia.

Faradic Applications.—These are not made with a view to causing muscular contractions, and the current must, therefore, be a weak one and preferably one with the most rapid possible interruptions. The latter are easily secured if the faradic coil is made with a ribbon interrupter. A strip of steel tape is the vibrator which interrupts the primary current. It is permanently fastened at one end and may be tightened by turning a screw at the other end. The tenser the steel ribbon the more rapid are the vibrations produced by the action of the electromagnet which is placed opposite the middle of the ribbon. The more rapid the succession of induced currents, the less is the effect in causing muscular contraction and the greater is the tonic effect upon the sensory nervous system. The faradic coil should have an adjustable number of turns in the secondary coil and the greatest number should be selected.

Almost every type of faradic coil gives currents which have perceptible polarity, but this is so very slight that either electrode may be used indifferently.

General faradization is useful in cases of neurasthenia. The patient sits upon or lets his feet rest upon a large sheet of metal covered with wet flannel as the indifferent electrode. The other electrode is passed

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[1] Traitement de la neurasthenie, Revue de Therapie, July 15, 1905.

[2] Manuel d'Electrotherapie et d'Electrodiagnostic, Paris, 1906.

over the forehead, the nape of the neck, the spine, the precordia, and the abdomen. This active electrode may consist of a damp sponge electrode or it may be the operator's hand. In the latter case the operator holds a metallic or sponge electrode connected with the active pole and the current passes through his body to the patient. The treatments last about ten minutes.

Beard considered general faradization as especially indicated in neurasthenia with myasthenia and malnutrition, and that it should be avoided in very excitable neurasthenics, for whom static electricity seems to be better.

Local Faradization.—Erb's treatment for cerebral or spinal neurasthenia is by local applications alone of faradization for only two to five minutes.

Bladder symptoms of a paralytic type in men may be treated by faradization with the indifferent electrode on the abdomen or buttocks, and the active electrode applied to the perineum and scrotum successively. Rapid interruptions and a fine secondary coil are used.

The pelvic neuralgia or neurasthenia in women is best treated by static electricity applied intravaginally, as has been described on page 505, or by vaginal faradization. For the latter, sponge electrodes are held in the vagina and over the abdomen. Very rapid interruptions and the maximal strength of current are used for ten minutes each day.

Galvanic Applications.—*General galvanization* is applied from a large indifferent negative electrode applied to the feet and an active positive electrode rubbed over different parts of the surface. Two to four milliamperes is the proper strength of current. Such an application is not very often employed.

Central galvanization may be used when the patient is well nourished, and his muscular strength has not been affected by the disease. A large negative electrode is placed over the epigastrium, and a small active positive electrode is applied successively to the forehead and vertex for one or two minutes, and then to the sides of the neck and down the spine for two to five minutes. A current of 8 to 10 ma. is used. but it must be gradually turned on for each position of the active electrode, and gradually turned off before the electrode is removed from each place. The strength of current may be a little greater at a distance from the head.

Local Galvanization.—The uniform and uninterrupted galvanic or constant current is used for two or three local conditions.

Impotence from neurasthenia in men may be treated by a current of 10 to 20 milliamperes, flowing for fifteen minutes between a large indifferent positive electrode at the genital center in the spine, and an active negative electrode passed over the perineum, scrotum, spermatic cord, and the root of the penis. Albert-Weil sometimes terminated each treatment by rhythmic galvanization. Treatments are given daily. Impotence is a condition in which the discovery and removal of the cause of the trouble is extremely important. Such a condition as hemorrhoids or rectal ulcer may interfere with the success of any treatment directed toward the genital organs alone, and then again every one realizes the profound influence of the mind over this condition.

Constipation.—This is almost always a condition of spasmodic contraction in neurasthenia and is relieved by the constant current of rather high amperage (15 or 20 milliamperes through large electrodes) over the abdomen. Other means are the static spark to the left iliac fossa, rhythmically varied and reversed currents, and galvanofaradization.

Cephalic Galvanization.—This is suggested by Leduc for cases of cerebral neurasthenia. A large positive electrode is placed at the nape of the neck and a negative electrode 5 by 10 cm. in size is placed on the forehead. The current must be turned on very gradually until 20 ma. are applied. This is continued for a quarter of an hour. There is an immediate sense of relief, clearness of thought, and ability to work. The wrong polarity—*i. e.*, with the positive pole upon the forehead—produces a disagreeable sensation of heaviness, slowness of thought, and somnolence.

Pneumogastric galvanization may be employed for the relief of cardiac palpitation and erethism. The positive electrode is placed in the mastoid fossa and the negative over the upper border of the clavicle an inch and a half from the sternum; a current of from 5 to 10 milliamperes is turned on gradually and allowed to flow for five or ten minutes. It is turned off just as gradually.

Very Heavy Galvanic Currents for Constipation in Neurasthenia.—This method, used by Hartenberg,[1] has not yet been generally tried. The patient is seated upon one electrode, and another as large as possible is applied over the abdomen. The current is of 40 volts and 200 ma. and is applied every thirty seconds for an instant, first in one direction and then in the other. Vigorous contractions of the abdominal and intestinal walls take place. There is no irritation of the skin. Forty such double shocks (closure and opening) are applied at first every day.

Galvanic Currents for Headache in Nervous Dyspepsia.—A current of 8 to 10 ma. is applied with one electrode at the nucha and the other on the forehead.

High-frequency currents have become a most important factor in the treatment of neurasthenia. The general indications as to tension have already been alluded to. The d'Arsonval, or low-tension high-frequency currents, are suited to cases with high arterial tension, and the Oudin and other high-tension high-frequency currents are suited to cases with low arterial tension.

Special Indications for High-frequency Currents in Neurasthenia.—*General electrization* by high-tension high-frequency currents is more frequently indicated than any other method except in cases with high arterial tension. A bipolar Oudin resonator or a pair of Guilleminot spirals are used and a metal plate connected with one pole is applied directly to the nape of the neck, while the other pole is connected with an effluve electrode held near the surface of the epigastrium; or this electrode may be a vacuum bulb rubbed over the surface of the abdomen. In either case the benefit is due to two factors—first, the surgings of high-frequency and high-tension currents through the patient; second, the ultraviolet rays produced by the effluve from the brush electrode, or by the shower of tiny sparks from the vacuum electrode. This liberates ozone from the atmosphere, which is carried into the system through the skin to produce a tonic effect. This application should last a quarter of an hour, and Albert-Weil finishes the séance by placing the fixed metal plate electrode over the epigastrium and passing the brush elec-

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[1] Presse med., March 7, 1906.

trode up and down the spine for ten minutes. In high-frequency treatment the metal electrode applied directly to the surface of the body may be considered the indifferent electrode. The brush electrode by which an effluve is applied, or the glass vacuum electrode with its shower of tiny sparks, either electrode making a direct application of ultraviolet radiations and of ozone, may be considered the active electrode. The nerve centers requiring especial tonic treatment in most cases of neurasthenia are the solar plexus and the spinal cord.

Low arterial tension is progressively improved by bipolar applications of high-tension high-frequency currents applied through a metal electrode at the epigastrium, and a succession of sparks of considerable size applied along the spine. A metallic electrode may be used for the latter purpose, but a glass vacuum electrode is much more convenient. A greater strength of current and a less close application of the vacuum electrode as it is passed over the surface makes the difference between sparks of considerable size and tiny or imperceptible ones. Moutier secures the same increase in arterial tension by sparks from a monopolar resonator, and the present author usually employs this method, which has the great convenience that it can be applied through the clothing. Albert-Weil thinks that the bipolar application is a little more effective.

Dyspepsia.—The pain is often relieved and the action of the stomach and intestines regulated by a bipolar high-tension high-frequency current from a metal electrode in contact with the back and an effluve or a vacuum electrode applied over the stomach.

Impotence.—One high-frequency application suited to this symptom in male neurasthenics is from a bipolar resonator, with an effluve over the epigastrium and a spark electrode applied over the genital center in the spinal cord.

The author has had successful results with a monopolar application from the Oudin resonator and a glass vacuum electrode to the penis, scrotum, and groins. A strong application is employed, regulated so as to produce a current which makes the glass quite hot, but with very little spark effect, powder being used to enable the electrode to slip smoothly over the surface without breaking the contact or producing perceptible sparks. No effect may be noted at the first treatment, but during the subsequent treatments the erections become extremely vigorous. Functional power is restored, but whether there is a relapse depends upon the patient's general condition.

A further consideration of the use of high-frequency currents in this disease is found on page 567.

ELECTRIC SLEEP AND ELECTRIC DEATH

Electric Sleep.—This is a name given to a form of anesthesia which Stéphane Leduc has been able to bring about in animals and in man as a result of the application of a type of electric current which he himself has devised. The current has already been spoken of in the paragraph on local anesthesia and the treatment of neuralgias. It is an intermittent current of low tension and of infrequent interruption, which passes through the entire body of the animal. The interruptions in the current, as has already been stated, run from 90 to 110 per second, and the electromotive force rarely exceeds 30 volts. The strength of current is 4 ma. The apparatus is described on page 475.

Leduc was able, in 1902–03, to bring about complete narcosis in animals by the application of his current directly to the cranium, one electrode being placed upon the head and the other either upon the extremities or over the abdomen of the animal.

The description of what takes place can perhaps be best told in his own words, for he made himself the subject of an experiment and his assistants placed him under general electric anesthesia.

The results of his experiments were communicated to the French Societé de Biologie, November 22, 1902, and in the Archives d'Électricité médicale, July 15, 1903, he gives us a description of his own sensations when passing into the electric anesthesia.

One large electrode formed of absorbent cotton impregnated with 1:100 solution of chlorid of sodium, with a metallic plate behind, is placed on the forehead and fastened to the head. This frontal electrode is the cathode. A larger electrode made in the same manner is placed over the back and fastened there by means of an elastic band. The Leduc current is then turned on, being interrupted for the first tenth of the period of application one hundred times to the second. The sensation produced by the stimulation of the superficial nerves, although slightly disagreeable, can be easily endured.

After a short time the patient feels a calm similar to the sensation produced by a continuous current, and this, after having passed its maximum, slowly diminishes, notwithstanding a gradual increase in the electromotive force of the current.

The face becomes red, slight contractions of the muscles of the face, neck, and even of the forearm occur, and fibrillary tremors of the extremities take place, then one feels a tingling of the extremities in the fingers and in the hands, which gradually extends to the toes and the feet.

At first an inhibition in the centers of language takes place, the patient is unable to express his thoughts, although he has active cerebration going on all the time. Then the motor centers are completely inhibited, the subject cannot react even to the most painful stimulations, he is unable to communicate with the experimenters although fully conscious.

The extremities, without being in a complete state of relaxation, did not show any particular involvements; certain choking or tremors, not corresponding to any painful impressions, may take place, but seem to be caused perhaps by an excitation in the muscles of the larynx. In his experience the appearance remains absolutely unaltered, the respiration perhaps a little diminished.

When the current was at its height, he describes his feeling as though he were in a dream, and although hearing things about him, he only half appreciated what was going on. He had a feeling of consciousness of his own impotence and inability to communicate with his colleagues. The contacts, the pinching and the pricking in the forearm, could be felt, but the sensations were much diminished, as in a very large swollen member.

The most painful impression was to notice the dissociation and the successive disappearance of the faculties; the impression was identical with that which one feels in a nightmare in which, in the presence of a great danger, one feels that one is neither able to cry out nor to make any movement.

In his first experiment consciousness was not entirely abolished, but in a second séance his colleagues advanced to the point where, so far as they were able to determine, consciousness had lapsed completely. but Leduc was able to feel that this had not really taken place because there was not complete suppression of all sensibility.

The electromotive force had been raised as high as 35 volts, the intensity in the interrupted circuit being 4 milliamperes. In each one of the séances he remained twenty minutes under the influence of the current.

Awakening was instantaneous and the after-effect was a mild state of exhilaration.

With animals, however, as has been shown by Leduc and his pupils and by many other observers, the electric sleep may be prolonged for considerable periods of time—for three or four hours at least—and operations may be performed upon them.

Certain points have been brought out with reference to this electric sleep which, although as yet not definite, may be outlined at this time. In order to produce the electric sleep according to the experiences which have thus far been reported, it would appear that the ordinary street current is not as valuable—or as safe, it would perhaps be better to say—as a current which is delivered more equably, as from a storage-battery. The street current which charges a storage-battery and is utilized from there would be the ideal current. The arrangement suggested by a number of experimenters would be to utilize the storage current for the electricity which is to traverse the body, and the street current to run the motor of the interrupter.

Gradual application of the current is to be preferred to an abrupt dosage.

The negative pole, the cathode, should always be applied to the head, for experience has shown that if the anode be applied to the head grave disturbances in respiration take place and the temperature is apt to go up.

Certain conditions are observed to be more or less constantly present. Thus the pupils are usually contracted during the state of electric sleep. The temperature is usually about normal or slightly above. The respiratory rhythm is slightly hastened. There is usually an increase in the arterial pressure which seems to depend upon vasomotor causes. Certain of the reflexes seem to be exaggerated, while others are diminished.

In overdosage, leading to an electric epileptic state or to electrocution by the Leduc current, the blood-pressure suffers a very marked fall and the respiratory inhibition is decided.

Whether the Leduc current can be used to advantage in electrocution of the human being is for the future to decide, but there are certain facts which point to its desirability in this direction.

As to its applicability in man for anesthetic purposes, the future alone will be able to determine. At the present time of writing the facts brought out by the application of this new type of current are of extreme theoretic importance, but it has not been tried in a sufficient number of cases to justify any general statements concerning its applicability for general narcotic purposes.

Local Anesthesia from Electric Currents.—This has been obtained by H. Günzel,[1] using a direct 25 to 30 volt current of 2 to 10 ma. interrupted 230 times a second. The anode is placed on the skin over the

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[1] Berlin. klin. Woch., 1908, No. 45.

painful spot and the cathode at some indifferent place. He has found it effective in migraine, bronchial asthma (with the anode on the neck), and angina pectoris.

Electric Death.—Internal lesions in death due to industrial electricity—pathognomonic lesions for the most part—have been absent in these cases. Numerous experiments have been made on animals to determine the causes of death and the character of the lesions. The earliest experimental investigations made on animals with the modern industrial electric currents that are of service in the present presentation were those of Grange, Gariel, and Brouardel, made in 1884, and those of Brown-Séquard and d'Arsonval[1] in 1886 and 1887. It should be borne in mind, however, that Priestly, as early as 1766, killed animals by static electricity, and that at that time numerous experimenters followed him, notably Fontana, the Italian physicist. The experiments of Nothnagel in 1880 are also worthy of record in this relationship.

D'Arsonval's results will be referred to under the paragraph on Causes of Death, since he was interested in the physiologic side of the problem only. From the pathologic point of view the investigations of Peterson and Doremus, conducted in the Edison laborities in 1888, are of interest.

Animal experiments made by Kratter[2] within recent years on mice, guinea-pigs, rabbits, cats, and dogs show certain signs regarded by him as more or less pathognomonic of the condition. Subpericardial and subpleural ecchymoses and, more particularly, subendocardial ecchymotic extravasations occurred in most of his cases, combined with bloody emphysema of the larger bronchial ramifications. These signs, when taken in conjunction with the external burns, are believed by him to be sufficient to make the diagnosis "death by electricity." Rigor mortis occurred very rapidly and persisted for a distinct period of time. Macroscopic changes in the brain and spinal cord were not prevalent, though in some there were subdural and intermeningeal hemorrhagic extravasations. These are of interest by way of comparison with similar findings by Peterson, and in cases of electrocution as reported by Van Gieson. Changes in the morphology of the blood have been emphasized by earlier observers, but the careful work of Kratter and other recent writers would seem to prove quite conclusively that such do not occur save at the sites of electrode contact. Cunningham[3] has shown that if the thorax be opened immediately following death due to strong continuous currents, the heart on close examination will be found to show a minute quivering throughout its entire muscular substance. While the coördinate beats of the ventricles, as a rule, are absent, the numerous isolated bundles of muscle-fibers will be found alternately to contract and relax with vigor in different parts of the ventricle; and as the right and left auricles become gradually distended this irregular quivering of the muscle bundles grows feebler and feebler, until every trace of muscular contraction has disappeared. This state of *delirium cordis* or, as Cunningham prefers to call it, "fibrillary con-

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[1] D'Arsonval, La morte par l'électricité dans l'industrie, Comptes rendus, April 4, 1887, vol. civ., p. 988.

[2] Kratter, Der Tod durch Elektricitat, Vienna, 1896, S. 61, *et seq.*

[3] New York Medical Journal, Oct. 28, 1899, pp. 581, 616.

traction," as the cause of death was first pointed out by Cunningham, and also independently by Prévost and Battelli.[1]

The nervous tissues have been carefully searched for pathologic changes, and it has only been within recent times that distinct changes have been found. It seems not improbable that changes of importance would be found by the newer technical methods of investigation, but thus far only a few workers have employed the Nissl methods, or modifications of the same. Kratter's observations were made by the older methods, and he found no special cell changes. He confirms the observations made by Peterson, Spitzka, Van Gieson, and others that minute capillary hemorrhages in the perivascular spaces are present, especially in the superficial layers of the cortex, but these he distinctly shows are not universal, and cannot be regarded as of sufficient moment on which to base a pathologic diagnosis of death. He concludes, however, that he believes that minute changes, not known to our present technical methods, are responsible for death by electric currents. More recently Corrado[2] has shown that such minute changes may be demonstrated by means of the more modern histochemic methods.

Corrado's conclusions may be summarized as follows:

The continuous electric current derived directly from the commutator and applied to robust adult dogs weighing from 2.5 to 20 kilos (5 to 50 pounds), one electrode being placed on the head and the other on the lower portion of the spinal cord, with a voltage of from 720 to 2175 volts, and an amperage of 20 to 30, or in two dogs, 10 to 12 amperes, produced death in every instance. Death occurred immediately and was not influenced by artificial respiration. On the closure of the circuit the animal, without emitting a cry, became rigid, and all the muscles, especially those of the back, contracted violently, producing a pronounced opisthotonos. This rigidity persisted for from one-half to one minute after the cessation of the flow of the current. Respiration was arrested from the first moment of the passage of the current.

An examination of the ganglion cells of the brain and spinal cord by the newer methods of Nissl and also by the method of Golgi showed a number of interesting lesions, the importance and interpretation of which are only just beginning to be appreciated.

Corrado describes changes as occurring in the external shape and configuration of the cell-body, changes of the cytoplasm and of the processes.

A. **Changes in the Cell Contour.**—(1) Noteworthy and various deformities, erosions, jagged outlines, lacerations, and even severe destruction of the cell outline. (2) The contour of the cell became hazy and diffuse. (3) In some cases the protoplasm became granular on one side.

B. **Internal Cell Changes.**—(1) A grade of dissolution of the chromatic substances with powdery granulations was observed. The cell contents were more homogeneous and showed the beginning changes of chromatolysis. (2) Frequent and pronounced vacuolation (perhaps artefact). (3) The chromatic substances had a slight tendency to become dispersed in the remainder of the cell-body, at times in distinct collections, which in certain parts of the cerebral cortex had a special

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[1] Comptes rendus de l'Academie des sciences, March 13, 27, 1899.

[2] G. Corrado, De alcune alterazione delle cellule nervose nella morte per elettricita. Atti. d. R. Assad. med. Chir. di Napoli, 1898, vol. lxxv.

arrangement. These collections of chromatic particles were not disposed in the direction of the passage of the electric current. (4) The nucleus is quite resistant. It may, however, be modified in shape, become diminished in size, or may entirely disappear. The contour of the nucleus may be irregular or even angular. The chromatic substance of the nucleus may be irregularly disposed, granular, arranged in fine, irregular filaments at the periphery, or it may entirely disappear, leaving the nucleus colorless. The position of the nucleus may vary. A certain tendency is manifest for it to be located on one side, especially to that side on which the accumulation of chromatic substances occurs. The nuclear membrane may be broken. (5) The nucleolus is the most resistant part of the cell. It is for the most part preserved and deeply stained, even when the remainder of the cell is profoundly altered. At times it may be diminished in size. It has a tendency to an eccentric position, being pushed out to the periphery of the nucleus or even to the periphery of the cell.

Corrado also describes a series of changes in specimens treated by the Golgi methods. These changes of the dendrites consist for the most part of varicose atrophy, fragmentation, and other modifications of shape and position. Since the Golgi method and its now known modifications show precisely such changes in normal material, it is fairly well established, by reason of this and also on account of the great lack of uniformity in the Golgi pictures, that it is unwise to describe these as degenerative lesions pathognomonic of any diseased condition. Hence, these observations of Corrado by means of the Golgi method are not considered final.

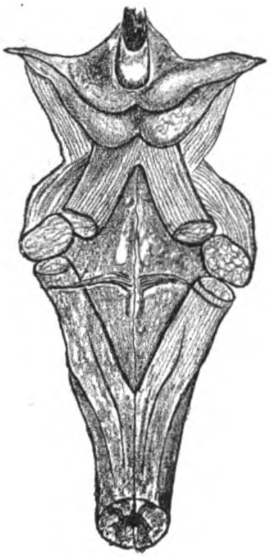

Fig. 321.—Showing the character and distribution of the petechial spots on the floor of the fourth ventricle in the case of Schichiok Jugigo (Van Gieson).

In man the pathologic features have been closely followed, though not as yet by the newer methods. Electrocution has given the most accurately observed cases, and the investigations of Spitzka, Van Gieson, and Kratter are the most elaborate. In the case of William Kemmler, the first officially electrocuted criminal under the modified statutes of the State of New York, the following autopsy record is taken from the notes of Dr. George F. Shrady: "Capillary hemorrhages were noted on the floor of the fourth ventricle, the third ventricle, and the anterior part of the lateral ventricles. The circumvascular spaces appeared to be distended with serum and blood. The brain cortex beneath the area of contact was notably hardened. The vessels of the corpora striata were notably enlarged at differents parts of their ramifications. The pons was slightly softened. The spinal cord showed no gross lesions." The abstracted report of the microscopic findings of Dr. Spitzka is as follows: The brain, spinal cord, and peripheral nerves appeared structurally healthy in every place examined except in the anemic and hardened areas. The hemorrhagic spots showed no vessel alterations. (The cytologic changes described by him are of little moment viewed from present day standards.) The vacuolation of the ganglion cells described are those now recognized for the most part as being due to manipulative artefacts, hardening etc., and cannot be brought into correlation with the later-day pathology of the ganglion cell (Ewing, Goldscheider, Turner, Barbacci, etc.). The histologic examinations of those paying the electrocution death penalty, made by Dr. Van Gieson and others, are more extended, and since newer methods of accurate fixation and staining were in vogue, some clue may be gained as to the amount of cellular change. The details of the visceral examination do not need repeating, since nothing abnormal has as yet been found in any of the viscera related in any way to the method of producing death. Of the cases examined by Van Gieson, that of Schichiok Jugigo may be taken as a type. "The pia was uniformly thin and moderately congested. The blood was fluid throughout. The vessels at the base of the brain were normal. The floor of the fourth ventricle at its upper half contained some dilated vessels, and on the left side there were a number of minute radiating petechial spots from 1 to 2 mm. in diameter. These small petechial extravasations showed small masses of extravasated red blood-cells, situated for the most part in the perivascular spaces just beneath the ependyma." The hemorrhage appeared as if a small vessel had given way, but whether such rupture was due to the current, to the muscular contortions, or to the effects of manipulation are not determined by the observer. In his summary of autopsy findings, after reviewing the result of a number of autopsies, Dr. Van Gieson notes the following: "(1) The passage of an electric current of the pressure employed in these cases (of approximately from 1400 to 1700 volts) and in this manner does not do any damage to any of the internal organs, tissues, or muscles. None of these parts are lacerated or changed in volume; neither are there any gross chemic or morphologic changes or alteration of their finer structural features. (2) The local thermic effects of the electrodes are

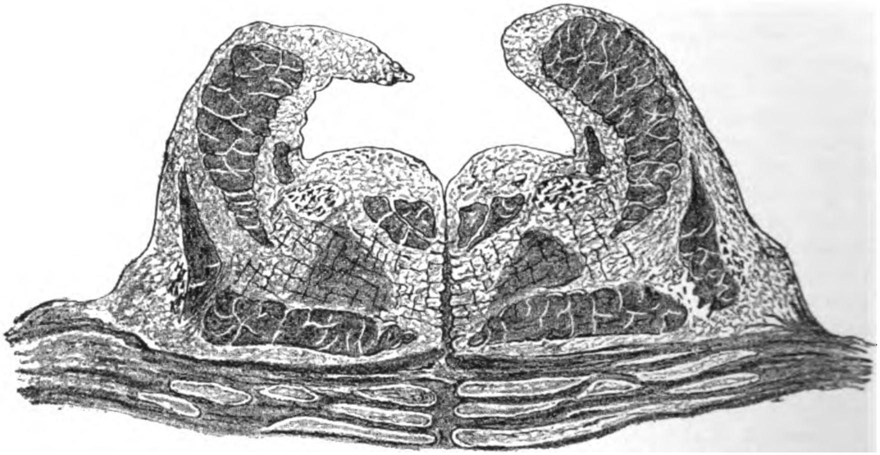

Fig. 322.—Showing the character and distribution of the petechial spots on the floor of the fourth ventricle in the case of Schichiok Jugigo (Van Gieson).

limited to the scarf-skin. (3) The occurrence and distribution of the minute hemorrhagic spots are not uniform or constant features in these cases and, as they are found after death from a great variety of causes, they cannot properly be regarded as positively characteristic of death by this method." Observations on man, which can be used to compare with those of Corrado on dogs, are still lacking. For man it cannot thus far be said, therefore, that the observations of Corrado on dogs have been verified.

PHYSIOLOGIC CAUSES OF DEATH BY ELECTRICITY

From the time when the gods were displeased with the children of men to the present, speculation has been rife upon the question as to the cause of death by electricity. The earlier observations have been collected by Arago,[1] and we are indebted to him for a large number of interesting facts. Among the earlier observers John Hunter taught that death was due to the "instantaneous destruction of the vital power." Brodie believed that the action was on the head. Edwards wrote of the disorganization of the nervous system. Robins claims that death was due to asphyxia. Schneider, in 1833, taught that the electric current did not traverse the body but spent itself on the surface, thus causing the extensive burns, and death was due to the shock of the nervous system. Stricker's observations were among the first series of studies of the more modern period. Reports of autopsies are more frequent from this time, and experimental work has been greatly amplified. It is worthy of mention in passing that Priestly, in 1766, and Fontana, in 1775, made a number of elaborate experiments.

The modern epoch of experimental work may be said to have been inaugurated by Nothnagel, of Germany, in 1880, by Brouardel, Grange, and Gariel, in 1884, in France, closely followed by Brown-Séquard and d'Arsonval in 1887, by Kratter in Germany, and by Biggs, Donlin, Houston, Jackson, Knapp, Peterson, Robert, and Terry in America, with the later studies of Tatum, Jones, Bleile, Oliver and Bolam, and Cunningham. From the pathologic point of view the work of Nissl, Hodge, Levi, Lugaro, Mann and Corrado[2] is to be borne in mind.

From the foregoing it may be seen that the entire possible theoretic ground was covered by the earlier observers, but their investigations lacked the precise experimental evidences demanded at the present time. The investigations of Nollet, Grange, d'Arsonval, Grasset, Dubois, Leduc, and others mark the earlier steps in the progress of the elucidation of our knowledge concerning the phenomena of death by electricity, while the investigators just mentioned have brought the question to the present time with some definite conclusions. d'Arsonval's and Brown-Séquard's earlier hypotheses were received more widely than those of the other writers, and have been extensively quoted, but within recent times many of their conclusions have been questioned. d'Arsonval taught that death was produced in either of two ways or, perhaps, by the concurrent action of both: (1) By direct action, during which the disruptive action of the current produced mechanic alterations in

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[1] F. Arago, Sammtliche Werke, Uber das Gewitter, Deutsch von W. G. Hankel, Bd. lv., Leipzig, 1854.

[2] For bibliography of this recent work, see Barbacci, Centralblatt für allgemein Pathologie, 17, 18, 1899; Jelliffe, Archives of Neurology and Psycho-Pathology, vol. i; Ewing, ibid; Turner, Brain, 1899.

the tissues and thus altered their physiologic activities. (2) By indirect or reflex action, whereby the important nerve-centers of the medulla were affected in their physiologic functions, which induced death.

Brown-Séquard later amplified this indirect action in the nerve-centers. d'Arsonval again brought up the question, first promulgated by Grange, that the electric current could bring about effects simulating death, but the subject could be revived by artificial respiration, to which reference will be made further in the discussion.

Cunningham's[1] very able summary of the experimental data following the epoch of d'Arsonval is here very freely used. The researches of later writers clearly led to the conclusions that neither the results of experiments on animals with strong electric currents nor the numerous reports of pathologic findings in the bodies of men killed accidentally by the electric currents of commerce or legally electrocuted by the high-tension current employed by the authorities in New York State, are in the least corrobative of the hypotheses of these French investigators. Cunningham's experiments bear out the conclusions of the later writers, who find that in the higher animals the chief lethal effect of both the continuous and the alternating currents is due to their action on the heart. Thus, in order to bring about fatal results very much stronger currents are necessary when the electrodes are applied to both sides of the head. A complication of the problem arises from the fact that death may take place in different ways, according to the path traveled by the electric current. Thus the work of Cunningham and others has shown that if death results from the more or less prolonged passage of a strong current through the exposed brain and upper spinal cord, the lethal effect is plainly the result of asphyxia, while in a second class, where the course of even a moderate current traverses the heart for a brief period only, the deadly result is due to the interference with the coördinating power of the heart, which takes place suddenly and is permanent, causing the central nervous system to die of anemia. A corollary of this fact is the indication that death by electrocution could be caused in a shorter time and with greater certainty if the electrodes were so placed that the greater part of the electric current were made to traverse the heart directly. The cerebrospinal arc should be included, however, in the path of the current in order to still the respiratory as well as the cardiac movements. As pointed out in the section on Pathology, the heart in animals killed by electric current is found to show a condition of "delirium cordis" or "fibrillary contraction." This is what leads Cunningham to assert that death by commercial electric currents, as well as death by electrocution, is due for the most part to the fact that the electric current induces fibrillary contractions of the heart. The summary of conclusions by Cunningham is here given: (1) Industrial electric currents, which traverse the whole body transversely or longitudinally in sufficient intensity, kill because fibrillary contraction of the heart is produced, and not, as has been hitherto surmised, by producing a total paralysis of that organ or by killing outright. (2) Such currents neither kill the central nervous system outright nor paralyze it instantaneously. Death of the nervous system from such currents is due to the total anemia following a sudden arrest of the circulation. (3) In rare cases, when an electric current traverses only the cerebrocervical portion of the nervous system in considerable

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[1] Cunningham, New York Medical Journal (*loc, cit.*).

intensity and for a considerable length of time, it may kill by asphyxia, consequent on a more or less complete inhibition of the respiratory movements, which occurs chiefly during the passage of the current. No existing facts warrant the conclusion that the medullary respiratory center is paralyzed or killed in such conditions.[1] (4) Industrial currents are practically non-lethal to frogs and turtles, as the condition of fibrillation quickly and spontaneously disappears from their hearts after the current has ceased to pass. Such animals can, of course, be killed by the very prolonged application of a current of moderate intensity or by a brief one of enormous voltage and large intensity. (5) Strong electric currents applied to the surface of the skin affect the heart in the same manner as currents of less strength do when they are applied directly to the exposed heart. (6) It may be possible for an electric current of enormous intensity and electromotive force to produce instantaneous death, either by its disruptive action or by producing an instantaneous heat coagulation of the cellular constituents of the body. Industrial currents do not kill instantly, although as a result of their action death rapidly occurs. The experience of individuals who have recovered from severe electric shock indicates that such a mode of death is not a painful one.

Since, from a pathologic point of view, the critical analysis of the cellular changes described by Corrado does not enable one to say what the *initial* cause of the cellular destruction may have been, the results of physiologic investigation must be accepted; and since independent observers—Cunningham, Prévost, and Battelli—have come to similar conclusions, it seems that the question of the cause of death by electricity has an authoritative answer in the conclusions just quoted.

The experiments of Prévost and Battelli, page 367, are of the greatest value. They show that with the same position of the electrodes currents measured in hundreds of volts kill by cardiac fibrillation; and currents measured in thousands of volts kill by respiratory paralysis.

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[1] Corrado's observations, while not disproving this statement, throw some important light on the pathologic processes taking place in the medullary centers.

HIGH-FREQUENCY CURRENTS

It will be remembered that when a discharge of electrostatic energy takes place from a Leyden jar the spark does not represent a single exchange of the exact amount required to equalize the electric condition of its two armatures. On the contrary, the state of equilibrium is reached by a series of oscillations back and forth at the rate of about 500,000 a second. This is somewhat analogous to the experiment with the pith-ball suspended between a positively and a negatively charged body. The ball swings back and forth, carrying each time a fraction of the charge from one and taking it to the other body, where it neutralizes that amount of electricity of the opposite sign. This back-and-forth transference continues until both bodies are in the same electric condition. The oscillations occurring in the case of a discharge between the positively and negatively charged coatings of a Leyden jar, or of a battery of Leyden jars (acting as the condenser of an induction-coil, for example) are infinitely more rapid than the oscillations of the pith-ball in the illustration. The relative electric condition of the two armatures undergoes 500,000 alternations a second, and if the human body is connected with both armatures the application is quite different from any form of galvanic or faradic current. It is more analogous to the static spark or breeze than to anything else, but at the same time with the best high-frequency apparatus a current of from 100 to 500, or sometimes 1000 or more, milliamperes passes through the patient. This current is of incomparably greater volume or amperage than that which passes between the poles of the most powerful static machine. The effect upon the patient is due to the self-induction in the coil uniting the two Leyden jars, which forms an essential part of all high-frequency apparatus.

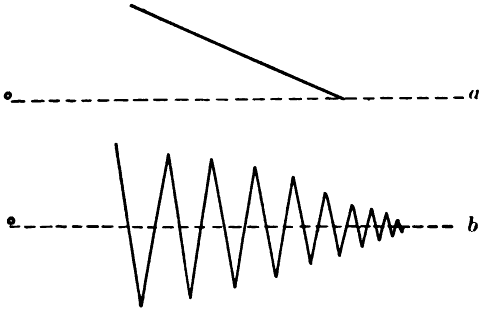

Fig. 323.—*a*, Simple discharge of high-tension electricity; *b*, oscillatory character due to the introduction of Leyden jars and a solenoid.

A simple discharge of high-tension electricity is undirectional, and Fig. 323, *a*, shows the way in which the strength of current gradually diminishes.

Fig. 323, *b*, shows the oscillatory character given to the discharge by the introduction of Leyden jars and a solenoid.

The oscillations in the currents, usually referred to as high-frequency currents and as the d'Arsonval, Oudin, and Tesla currents, are of the type above described and are called damped oscillations. This is because they quickly diminish in extent and die out, while undamped oscillations are uniform in extent. High-frequency currents with undamped oscillations are referred to under the heading of DeForest Needle and Duddell's Singing Arc (page 618).

The Direction of High-frequency Discharges.—The discharge of a Leyden jar may be made up of millions of oscillations, but if it is charged from a non-alternating source of electricity, like a static machine, the first and strongest oscillation is always in the same direction. The latter is also the case with high-frequency apparatus actuated by an induction-coil, because only the break discharges of the latter are usually operative; the weaker make discharge is unable to charge the condensers to the discharging point as indicated by the length of the spark-gap.

The Fleming Rectifier for High-frequency Currents.—This consists of an incandescent electric lamp in which there is a little metal cylinder besides the carbon or metallic oxid filament. Alternating high-frequency currents can pass through such a lamp in practically one direction only. When the filament is incandescent the partial vacuum in the globe becomes much less resistant to the passage of a current. The filament acts as a cathode, while the metal cylinder has a comparatively small surface for the radiation of cathode rays during the period when the current seeks to flow in the other direction. The incandescent lamp is lighted up by the current from a storage-battery.

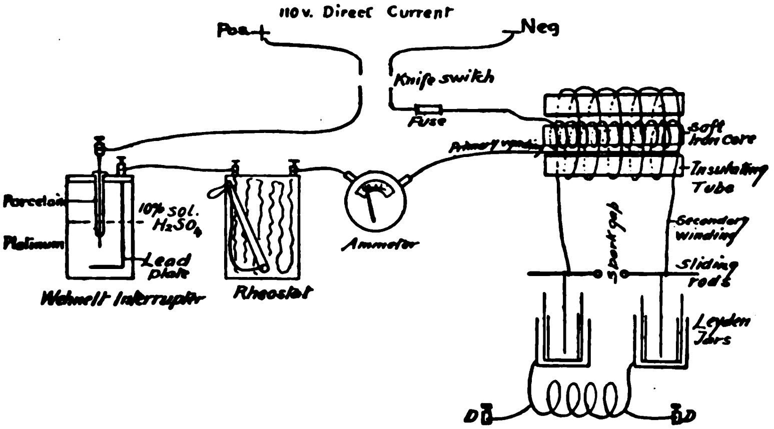

Fig. 324.—Apparatus for high-frequency current.

It is necessary to recharge the Leyden jars each time that they are discharged, so as to produce a certain continuity of effect in therapeutics. The rate at which the Leyden jars are charged and discharged is only a few hundred or a few thousand times a minute. The rate of oscillation in each individual discharge is millions of times a second. It is the latter rate that gives the name "high frequency" to these currents.

At the present time it is not possible to obtain directly from any make of static machine or induction-coil a high-frequency current. In order to obtain a high-frequency current from either the static machine or induction-coil it is necessary to have an additional piece of apparatus. The term "high-frequency current" should always have in addition the name which designates its particular type, such as d'Arsonval high-frequency current or Tesla high-frequency current. In both of these the frequency is high, but the physical characters of the current are entirely different. Fig. 324 illustrates a complete arrangement such as will be necessary to produce the d'Arsonval current from the 110-volt direct current; positive and negative indicate the 110-volt direct current, then comes an ordinary double knife-switch with fuse.

The positive wire is conducted to the platinum point of the Wehnelt interrupter. This consists of a glass or porcelain jar containing a 10 per cent. solution of sulphuric acid. Mounted on the cover is a porcelain stem having an opening at the lower end through which is passed a piece of platinum wire. This usually has a mechanism for regulating the length which it extends beyond the porcelain stem. In addition there is a connection with the plate of lead. The plate of lead is connected with one terminal of the rheostat; the other terminal of the rheostat with one terminal of the ammeter; the other terminal of the ammeter with one terminal of the primary; the other terminal of the primary back to the negative terminal of the 110-volt current.

The primary has a core consisting of a bundle of soft iron wires. This is held together by insulating materials, and on this is wound the primary wire, which may consist of one or more layers of copper wire of any desired diameter. This is placed inside of the insulating tube which may be made of hard rubber or micanite. On this insulating tube is mounted the secondary winding of the coil; the ends of the secondary winding are now connected with two sliding rods; these in turn are connected with the inside coatings of two Leyden jars. The outside coatings of the Leyden jars are connected by means of a coil of heavy copper wire which is known as the small solenoid of d'Arsonval. The patient is connected with the two terminals marked *D*. The strength of the current as applied to the patient is regulated by means of the spark-gap and by the strength of current used in the primary of the induction-coil. The current which passes through the patient is what is known as the d'Arsonval high-frequency current.

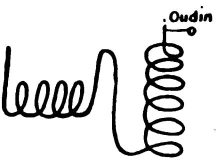

Fig. 325.—An early type of Oudin high-frequency apparatus.

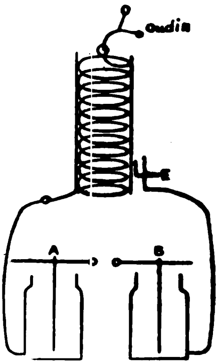

Fig. 326.—Oudin resonator.

In place of the electrolytic interrupter a mechanic interrupter may be used. In order to obtain the d'Arsonval high-frequency current it is absolutely necessary, using the usual induction coil and 110-volt direct current, to have the above-described arrangement.

D'Arsonval and Oudin High-frequency Apparatus.—D'Arsonval also made what is known as the large solenoid. Dr. Oudin found that by connecting one end of the large solenoid of d'Arsonval with one end of the small solenoid of d'Arsonval, as shown by Fig. 325, that from the terminal 0 he obtained a current entirely different in character from the ordinary d'Arsonval current. He also found that by adjusting the contact point between the large solenoid and the small solenoid he was able to regulate the discharge from the terminal 0. This led him to construct what is now known as the Oudin Resonator (Fig. 326). This you will see is simply a combination on one tube of the small solenoid of d'Arsonval and the large solenoid of d'Arsonval. In this construction, however, it is arranged so that the contact E is adjustable and it is found that when it is placed at a particular point the discharge from terminal 0 is at its maximum. As this contact-point is moved above or below this particular point the discharge decreases. When it is adjusted to produce its maximum effect the apparatus is said to be in resonance.

Another arrangement for obtaining high-frequency currents consists in what is known as a high-frequency set. This is designed especially to operate from the 110-volt alternating current (Fig. 327). It makes a somewhat more simple construction than the usual induction-coil arrangement, as it does away with the electrolytic or mechanic interrupter, owing to the fact that the current is alternating. In this arrangement, instead of the usual open magnetic circuit type of induction-coil, the closed magnetic circuit type is used. The alternating current is conducted to the double pole knife-switch; then one terminal is carried to either the metallic rheostat or what is known as an inductance regulator. This is then connected with one end of the primary, the other end of the primary to one terminal of the ammeter, the other terminal of the ammeter back to the main line. The secondary circuit is connected with the Leyden jars, which are connected with the Tesla coil. The current is regulated by means of the inductance and the length of spark-gap. In place of a Tesla transformer the secondary can be connected with an Oudin resonator. At the present time it is not possible to obtain a high-frequency current in any other than by the above or similar means. You cannot obtain a high-frequency current direct from either the induction-coil or the static machine. With either of these it is necessary

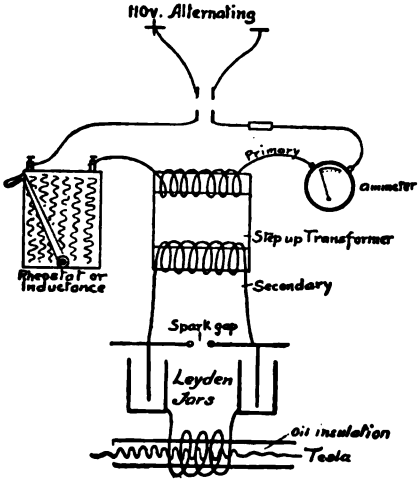

Fig. 327.—Tesla high-frequency set.

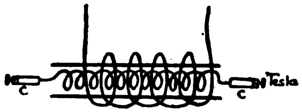

Fig. 328.—Detail of Tesla coil.

to have the arrangement of d'Arsonval, the arrangement of Tesla, or that of Oudin in addition to the static machine or coil. I call attention to this particularly, as some manufacturers claim that their static machine will give a high-frequency current direct. They use in conjunction with the static machine a vacuum electrode, and, as a rule, it is connected up as shown by Fig. 329. When the vacuum electrode is placed in contact with the patient it will light up with a violet color the same as it would if attached to a high-frequency apparatus, but the sensation produced in the patient is entirely different, being of a vibratory character; it is, in fact, when used in this way in conjunction with a static machine simply a method of applying the wave-current by means of vacuum electrodes. This current has a certain therapeutic value, but should not be called a high-frequency current. It will be referred to as vibratory current (Figs. 329 and 330).

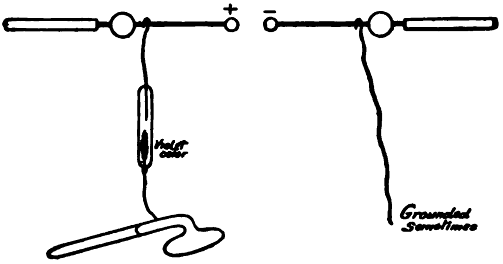

Fig. 329.—Connection when vibratory current is used with static machine.

One very simple test to demonstrate physically the difference between this current and either form of high-frequency current is to have the subject come in contact with the metal part which holds the vacuum electrode. When this is connected with the static machine as above described, you will experience a very disagreeable shock, whereas, when it is connected with a high-frequency current no sensation other than that of having a slight feeling of warmth will be experienced. Vacuum electrodes are used in this same way with an induction-coil,

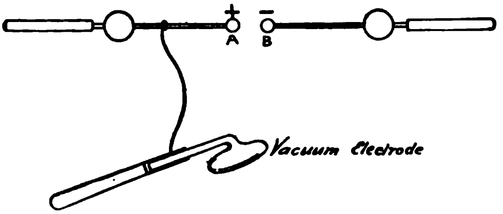

Fig. 330.—Connection when vibratory current is used from x-ray coil.

the strength of current being regulated by the distance A and B are separated.

In order to demonstrate the fact that this current is not a high-frequency one, it is only necessary to insert between the electrode and the apparatus a little instrument known as the oscilloscope. Fig.

331 shows this in circuit with a Tesla current. With the static machine you will notice that the violet color is all on one side of the center, whereas when connected with the Tesla current it shows the violet color on both sides of the center.

An **induction-coil,** such as is suitable for *x*-ray work, is very desirable for high-frequency apparatus. A 12-inch coil is about the best, and can be used no matter what the nature of the interrupter and the source of the primary current are. The primary winding of the coil should have a large number of turns so as to give great self-inductance and a proportionately heavy secondary discharge. In this case the actual spark length seems to be of less importance than the "fatness" of the spark, and in my own apparatus the best results are obtained with an adjustment which will produce a 6-inch flame between the poles of the coil when the high-frequency apparatus is disconnected from them. Every *x*-ray coil should have a variable primary winding, and if this is the case it will be easy to adjust it for the best high-frequency work. A desideratum is an interrupter which will produce a sufficiently heavy spark with only one, two or three, four, or five amperes of primary current. This means less wear upon the apparatus and longer continuous use without detriment.

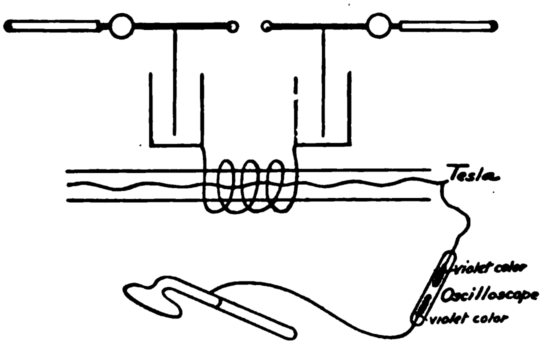

Fig. 331.—Oscilloscope demonstrates oscillatory character of Tesla high-frequency current.

With **alternating currents** an *x*-ray coil with one of the rectifiers described on page 699 works very well, or Gaiffe's transformer outfit may be used.

Gaiffe's transformer outfit, without any interrupter, for *x*-ray and high-frequency apparatus, is described in detail on page 719. The ordinary alternating electric-light current passes through a primary wire, which surrounds one part of the circumference of a magnet which forms a complete ring. Around another or the same part of the ring is wrapped the secondary wire. The voltage in the secondary wire is as many times the original 110 volts as its number of turns of wire is times the number of turns in the primary wire. The magnetic ring, with its primary and secondary windings, constitutes a transformer; in this case a step-up transformer, since the voltage is increased by it. The switches and liquid rheostats and condensers are all arranged as for *x*-ray work, but the two ventril tubes need not be used. Connection is made from the two *x*-ray terminals to the high-frequency apparatus.

Such an outfit will work continuously for an indefinite length of time and with absolute uniformity. It is the very best for use with an alternating current, and may prove to be so much better than an induction-coil and interrupter that, even with a direct current, it will be advantageous to use this outfit in connection with a motor generator by which the direct current is made to produce an alternating one.

The **d'Arsonval transformer** is one of the simplest and best forms of apparatus for the production of high-frequency currents. In this apparatus the poles of an ordinary induction-coil, such as an *x*-ray coil, are connected with the inner coatings of two large Leyden jars, and these inner coatings are further connected with the two terminals of an adjustable and enclosed (muffled) spark-gap. The outer coatings of the Leyden jars are connected with each other by a solenoid, which is a coil of heavy wire wound in the form of a hollow cylinder. The turns of this wire, about twenty in number, are about half an inch apart, and require no further insulation from each other. Conducting cords also pass to the patient from turns near the ends of the solenoid. One of these cords terminates in an ordinary metal handle, which is usually held by the patient. The other sometimes terminates in an insulated handle held by the operator. This has a metallic socket, into which fit electrodes of metal or of glass; the latter are vacuum tubes of various kinds, or this wire may terminate in the metallic plate of an autocondensation couch, or neither wire may go to patient, but they may lead to opposite extremities of an autoconduction cage.

The poles of the *x*-ray coil are widely separated; the points of the spark-gap of the d'Arsonval transformer are separated about one-third or one-half inch and a sufficient current is turned on to cause a rapid and uniform succession of sparks across the spark-gap. The latter is muffled, enclosed in a glass cylinder or vulcanite box to deaden the noise. Nitric acid fumes are generated by the passage of these sparks through the nitrogen of the air and a metallic nitrate is deposited upon the interior of the glass, which eventually interferes with the spark-gap by short circuiting and requires to be cleaned out. The patient, holding one of the handles in one hand and a vacuum electrode in the other, will experience no sensation but that of a gradually developing warmth from the vacuum electrode. This is true even with a current of 200 to 500 milliamperes passing through the patient. The vacuum electrode becomes lighted up by waves of violet light passing down inside the tube, succeeding each other at a rate which seems to be the same as that of the sparks across the spark-gap. This is ordinarily at the same rate as the interrupter. A hot-wire milliamperemeter, placed in series with the patient, shows the strength of the current. If the electrode is not in good contact with the skin, sparks may be seen beginning at some little distance and passing along the outside of the glass to the skin. There is also a production of ozone from the same sparks. There is no spark-gap in circuit with the patient. He is on a shunt circuit with the solenoid, and the fact that he gets any current at all is due to the heavy impedence in the solenoid developed by its self-induction.

To light an incandescent lamp by direct conduction of high-frequency currents two persons hold each a metallic electrode from one pole of the d'Arsonval transformer and each by his other hand holds one of the wires leading to an electric lamp suspended between them.

The lamp may light up brightly and still the persons experience no sensation from the current passing through their bodies.

The *author's vacuum electrodes,* with a vacuum of about $\frac{1}{1000}$ of an atmosphere, are made with a leading-in wire passing just through the thickness of the glass at the point where the tube has a screw thread. The tube is screwed into a metal socket well up inside of a special handle of hard rubber, which is completely insulated. No current can be received by either the patient or the operator from any part of the handle. The glass electrode is the only bare part, and contact with that is not disagreeable at all, although the current may be sufficient to light up a 16-candle-power lamp placed in circuit with the patient. Those for the surface of the body are simple tubes with a dome-shaped extremity, while some of those for the mouth, rectum, or vagina have an insulated stem where they enter the cavity and where sparks might occur from the contact being less perfect than further in where it is surrounded by mucous membrane. This insulation is accomplished by having the vacuum tube very small along this portion of its length, and having an air-space between it and an outer tube of glass, which is of uniform caliber with the portions of the electrode above and below it. The waves of light may be seen in the upper and lower and the narrow central portion, but are absent from the outer jacket surrounding the latter, and no current is obtained by touching this outer jacket.

Other vacuum electrodes are made without any wire, the current being of sufficiently high tension to penetrate glass of any reasonable thickness. In this case, to obtain a sufficient current the glass should be quite thin and there should be a large area of contact with the metal handle to avoid overheating the glass at that place. Different forms of metal and glass electrodes for various parts of the surface and for the different orifices of the body are made, and will be considered in detail in the section upon the Therapeutic Application of High-frequency Currents.

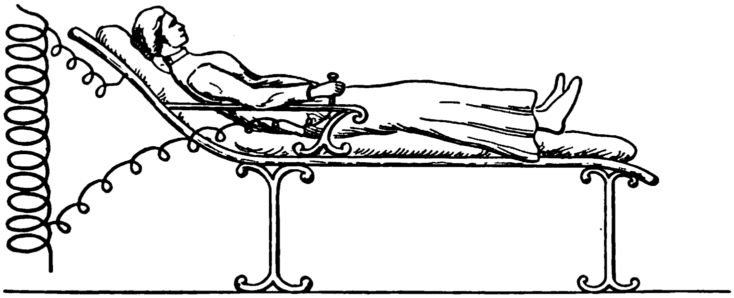

Fig. 332.—Autocondensation couch.

The **autocondensation couch** consists of a sheet of metal or a flat mass of wires connected with one pole of the d'Arsonval transformer, on top of which is a thick insulating mattress upon which the patient lies. The handle from the other pole of the d'Arsonval transformer is held in the patient's hand, and when the apparatus is in operation a current of 100 to 400 milliamperes is indicated by the meter which is in circuit with the patient. The patient becoming charged with one kind of electricity and the metal plate with electricity of the opposite sign, and the insulating mattress intervening, form a complete condenser on the same principle as a Leyden jar. The patient corresponds to the external metallic coating or armature of the Leyden jar, and each time the patient and the metal sheet become overcharged and a discharge takes place across the muffled spark-gap of the d'Arsonval apparatus the patient undergoes a very great number of electric oscillations.

In another couch which the author has used the principle is rather that of autoconduction. The couch consists in some cases of a wire mattress in two parts, very heavily insulated, each end being connected with one of the poles of the d'Arsonval. High-frequency currents are produced in the patient by induction from the wire couch without any metallic connection reaching the patient.

Another couch consists of *indurated fiber* an eighth of an inch thick, upon the back of which is a sheet of x-ray metal, and this covered again with a light insulating cloth. This is made in two sections, hinged together with quite a wide insulated separation, the wire from one pole of the d'Arsonval passes to one metal sheet, and the wire from the other pole to the other metal sheet. A convenient way to use it is to place it on an ordinary chair so that one part forms the seat and another the back. There should be no metallic parts to the chair except the ordinary nails and tacks. Before the patient is seated upon this the current shown by a milliamperemeter in circuit with the couch may be 150 milliamperes, and the moment the patient sits down it may increase to over 400 milliamperes. This is without any sensation. Through the patient's back he receives an induced charge from one metal sheet, and through the lower part of the body and the thighs he receives an induced charge of the opposite sign from the other metal sheet. Thus, an extremely rapid series of condenser discharges is produced through the patient's body. If a stronger current is turned on, 500 or 600 milliamperes, considerable brush discharge passes to the patient through the indurated fiber. While this is not disagreeable or harmful for a short time, it is better to avoid it in general.

With the autocondensation couch used by the author the current may be between 400 and 500 milliamperes when the patient is seated upon it and thus by a conductor effect facilitates the discharge. And when the patient leaves the couch the current will be seen to diminish to about 100 milliamperes. It will be remembered that if two Leyden jars are hung from the prime conductors of a static machine and a metal rod connects the outer layers of the jars, tremendously powerful white sparks pass between the poles of the coil. These are a thousand times louder than the discharge which takes place when the rod is disconnected from the outer layers of the Leyden jars. The wonderful discharge which takes place between the poles of the static machine when the rod is in place is accompanied and, one can almost say, produced by a similar discharge which passes through the rod. In the autocondensation couch in question the lead plates to which the wires lead from the high-frequency coil correspond to the inner coatings of the two Leyden jars in the experiment with the static machine. The patient's body corresponds to the outer layers of the two Leyden jars and the rod connecting them. The difference between the number of milliamperes going through the wires passing to the autocondensation couch, with and without the patient, shows roughly the amount of electricity induced in and discharging through the patient.

The autoconduction cage is a hollow cylinder formed by a coil of wire the turns of which are widely separated. The cage may be placed vertically, and the patient stand or sit inside of it, or it may be horizontal and surround a table top on which the patient lies. Its two extremities are connected with the two poles of the d'Arsonval transformer, and when in operation high-frequency currents are produced in the patient without his being in metallic connection with any part of the apparatus.

Measurement of High-frequency Currents in Autoconduction.—The most practical measurement of the strength of the current induced in the interior of the autoconduction cage is in Gausses, as described by Doumer, and depends upon the amount of current induced in a loop of wire placed inside the autoconduction cage and parallel with its turns. The currents are alternating, and the amperemeter is usually a thermic or hot-wire instrument. The graduations may be directly in Gausses.

The *frequency of the oscillations* in high-frequency currents may be measured by Ferrie's *ondometer*. This has a certain length of wire, which may be placed parallel with and close to the wire through which the oscillatory current is passing. The wire mentioned forms part of a circuit which also contains a self-induction, a condenser of adjustable capacity, and a hot-wire milliamperemeter. The capacity of the condenser in the ondometer is regulated so that the maximum current is registered, indicating oscillations synchronous with those in the circuit to be tested. The condenser is graduated in figures representing the number of oscillations per second. This is between 300,000 and 600,000 for most high-frequency work.

Effects of Autoconduction and Autocondensation.—With both the autocondensation couch and the autoconduction cage the patient does not feel any electricity, but its presence may be proved by drawing sparks from any part of his body and even a slight violet brush discharge may take place between the patient's two hands if one finger of each are brought lightly together. A variety of experiments may be performed with incandescent lamps or telephones to demonstrate the presence of electricity on every portion of the patient's surface.

To light an incandescent lamp by autoconduction it is only necessary to connect it by a loop of wire held inside a solenoid traversed by high-frequency currents. A vacuum tube approached to the solenoid lights up. Any body inside a solenoid is itself traversed by high-frequency currents.

Piffard's Hyperstatic Transformer (Fig. 333).—This apparatus is devised to obtain high-frequency currents from the static machine. Two medium-sized Leyden jars have their inner coatings connected with the two prime conductors of the static machine. The spark-gap is obtained by separating the poles of the static machine about an inch. The outer layers of the Leyden jars are connected with the extremities of a small solenoid, at the ends of which are binding-posts. With the plates revolving at the rate of 300 or 350 times a minute there is an effluve to be felt from both binding-posts, that corresponding to the positive pole of the static machine being the stronger. For mild applications a vacuum electrode is connected with only one (the positive) pole of the hyperstatic transformer. For a more active effect the patient holds a metal electrode connected with one pole while a vacuum or a metal electrode from the other pole is applied to the region to be treated. Piffard's own belief is that the hyperstatic current is chiefly valuable for a local effect, as in chronic eczema, and that it cannot take the place of the d'Arsonval current, with its vastly greater amperage, for the production of constitutional effects. The static machines usually found in Europe scarcely amount to more than laboratory toys. It is only the large American machines with eight or more pairs of plates, 30 inches or more in diameter, that are suitable for this therapeutic application.

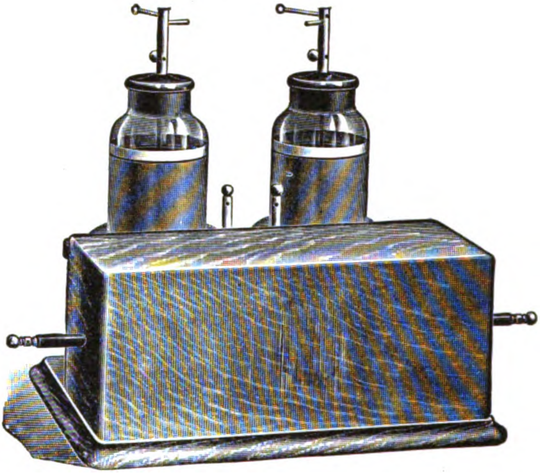

Fig. 333.—The Piffard hyperstatic transformer.

THE OUDIN RESONATOR

We come now to another type of high-frequency apparatus in which a condenser discharge is passed through one or more turns of an ascending spiral of which the upper end is free. The self-induction in the spiral increases toward its extremity, where the tension is such that the wire gives off an effluve or brush discharge of several inches into the empty air and a much more powerful one if some conductor like the human body approaches it. Quite a usual model is shown in Fig. 334. The poles of the induction-coil, or static machine, or transformer, are connected to the inner armatures of two Leyden jars (the condensers), and these same inner armatures are connected with a muffled spark-gap. The outer armatures of the two Leyden jars are connected by a solenoid just as in the d'Arsonval transformer, but in addition a wire passes from one end of the solenoid to the lower extremity of the vertical coil (the Oudin resonator proper) and another wire passes from an adjustable contact, usually near the middle of the small solenoid, to another adjustable contact with the Oudin resonator, usually about one-fifth of the distance from its lower pole. The adjustment between the amount of self-induction in these two coils produces harmony in the electric oscillations, and it is from this resonance that the apparatus derives its name. In order that this shall work well it is necessary to choose the proper turn in the spiral to which the second

Leyden jar shall be connected. This is done by starting the Ruhmkorff coil and then making a connection with the different turns successively.

Another form of resonator used by the author is made in the shape of a flat spiral, the outer end of which is soldered to the next turn of the wire and is also connected with one end of the small solenoid. The other end of the small solenoid may be connected with either the second, third, or fourth turn of the spiral. The center or inner end of the flat spiral is free, and corresponds exactly with the upper free end of the upright cylinder type of Oudin. In my model the spiral is 30 inches in diameter, and there are binding-posts at different parts to enable various strengths of discharge to be used. The effluve from the middle of the spiral is very powerful. The coil is large and heavily insulated and the turns of the spiral are about 1 inch apart.

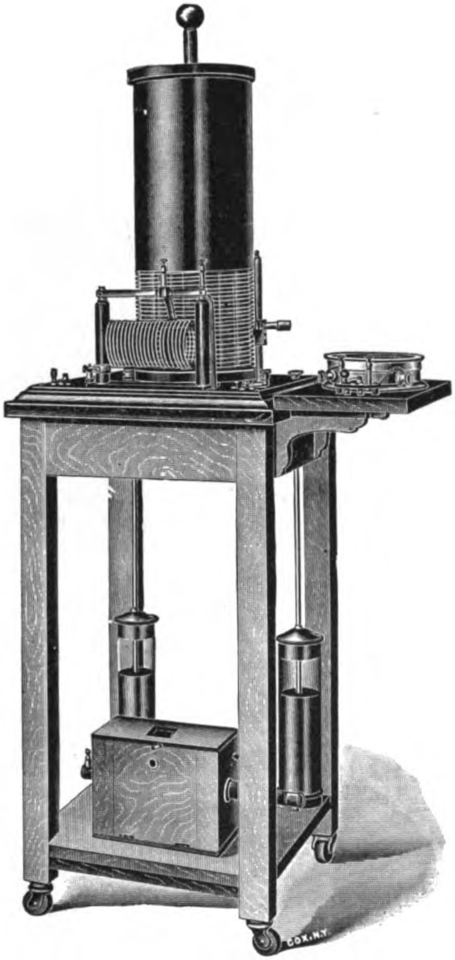

Fig. 334.—The Oudin resonator and d'Arsonval high-frequency apparatus.

The Oudin resonator is intended principally for unipolar applications, either as an effluve from pointed electrodes held at a distance from the surface of the body, or by direct application from vacuum or other electrodes applied to the skin or mucous membranes.

It requires at least a 12-inch induction-coil to actuate an Oudin resonator to the best advantage.

Bipolar applications with the Oudin resonator may be made by the effluve from two resonators applied, for instance, to the front and back of the chest, or the metal plate of an autocondensation couch may be connected with one resonator and an effluve from another resonator be applied over the patient. When two resonators are used the lower pole of each is attached to the opposite ends of the small solenoid. When the resonator is connected with an autocondensation couch the full strength of discharge should not be used. It would be likely to cause painful sparks.

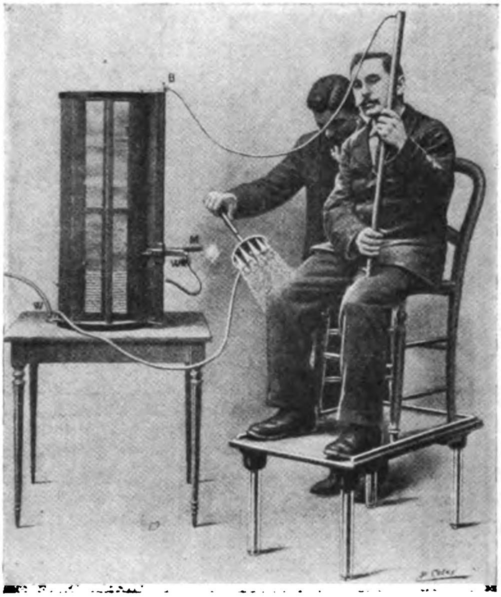

Fig. 335.—Effluve from bipolar Oudin resonator.

In one apparatus the outer armatures of the Leyden jars are connected directly with the Oudin resonator, one with the lower pole and the other several turns higher. These lower turns of the resonator produce the same effect as the small solenoid and enable this to be dispensed with.

Many other combinations of Leyden jars and coils have made for high-frequency currents.

TESLA HIGH-FREQUENCY CURRENT

In order to obtain this from the 110-volt direct current it is necessary to have all the apparatus as described for the d'Arsonval current, and in addition, as shown by Fig. 327, p. 521, and insulating tube is placed inside or outside of the small solenoid of d'Arsonval, and then a winding of very fine wire is placed either inside of the tube, if the tube is placed inside of the small solenoid, or outside of the tube if the tube is placed over the small solenoid. As described by Tesla, there is in addition to this insulating tube a liquid insulator in the form of oil, but as the apparatus is ordinarily constructed for medical purposes the oil insulation is not required. From the terminals C the Tesla high-frequency current will be obtained.

The **Tesla transformer** is a source of extremely high potential discharges at a rapid rate, and can be used to excite an Oudin resonator for medical purposes, but is more suitable for exciting Hertzian waves in wireless telegraphy. The transmitter for the latter consists essentially of a Tesla transformer and an Oudin resonator, whose upper terminal is carried to the top of the mast of a ship or of a high flag-pole if on shore. The Tesla transformer consists first of a primary coil, through which flows a rapidly interrupted current of high voltage from an induction-coil or from a step-up transformer; this primary coil is surrounded by a secondary coil, consisting of a large number of turns of very fine wire, and the originally high tension is enormously multiplied. Other essential parts of the Tesla transformer are the condenser and an adjustable spark-gap between the extremities of the primary coil. The condenser and spark-gap serve the same purpose here as in the d'Arsonval transformer to be described later. Both the primary and the secondary coil and the condenser are immersed in oil to prevent sparking from one coil to the other. The terminal poles of the Tesla transformer are wide apart, and the discharge from them is of altogether extraordinary power. To excite an Oudin resonator one terminal of the Tesla transformer is grounded and the other terminal is connected with the Oudin resonator at the height found to produce the best results.

Dr. Henry G. Piffard of this city modified the original Tesla apparatus so as to make it applicable to any static machine, and in order to differentiate it from an apparatus operated by a coil he called it the hyperstatic transformer. At the present time we have practically only two forms of high-frequency currents in use in medicine. These are the d'Arsonval high-frequency current and the Tesla or Oudin high-frequency current, The therapeutic applications of the Tesla and Oudin currents are identical, the other physical characters are also identical, the only difference being in the mechanic construction of the apparatus itself. In a general way the therapeutic applications of the two forms of high-frequency currents are as follows: The d'Arsonval, which is a low-voltage high-frequency current of comparatively high amperage, is used for its constitutional action. The Tesla and Oudin resonator currents are currents of high frequency, high voltage, and comparatively low amperage. They are used mostly for their local and reflex effects.

Violet-ray Treatment.—This is a term which has been used very carelessly, as there is really no such treatment. It has usually been applied when a vacuum electrode is used, without regard to whether the current was a high-frequency one or simply a high-voltage one, either being sufficient to cause the violet color to appear in the electrode.

Ultraviolet-ray Treatment.—This is another term which has been very carelessly used, it being applied when a vacuum electrode is used. As the ultraviolet ray will not penetrate the thinnest piece of mica or celluloid, the results which have been obtained when using the vacuum electrode are due to the form of current applied, and not so much to the ultraviolet rays, which are given off from the sparks outside of the electrode. Whenever a spark takes place there is a generation of ultraviolet rays, but these rays are invisible to the human eye.

All high-frequency currents are oscillating, but all alternating currents are not oscillating, as shown by Fig. 336.

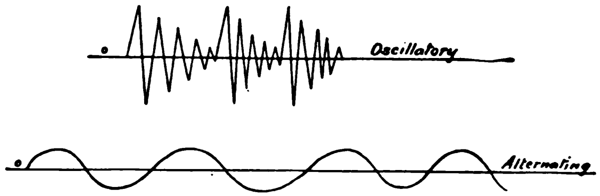

Fig. 336.—Difference between oscillatory and alternating currents.

Monolith Condensers for High Frequency.—These are condensers made in the form of flat plates of glass, between which are the metallic sheets which form the armatures of the condenser. The glass plates project beyond the edge of the metal and are soldered together by a cement of a glass-like consistence. Loss of electricity is prevented much better than by air or oil insulation of the armatures. The capacity of each is about the same as that of a large Leyden jar; the condensers are flat disks about 1 inch thick and about 8 inches in diameter. They may be combined in series or in quantity, and may be placed in the bottom of the resonator for instance.[1]

In many German high-frequency apparatus the adjustable spark-gap is in the self-induction line between the two external armatures of the condensers (Fig. 337) instead of between their internal armatures as in the d'Arsonval and Oudin and Guilleminot arrangements.

METHODS OF APPLYING HIGH-FREQUENCY CURRENTS

Applications from a Small Solenoid.—Instead of wires leading from the external armatures to an autoconduction cage, two wires lead from different turns of the small solenoid directly to two electrodes

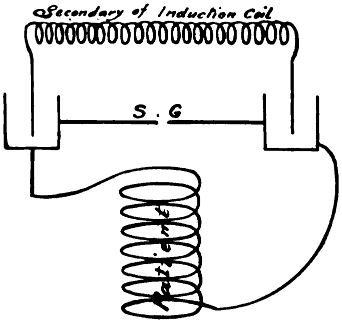

Fig. 337.—A German high-frequency apparatus with spark-gap between external armatures of Leyden jars.

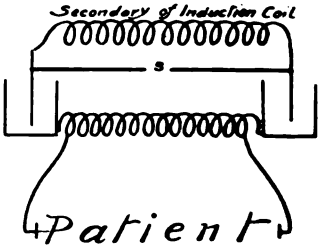

Fig. 338.—Application of high-frequency currents from d'Arsonval's small solenoid.

applied to the patient. The effect is due chiefly to the small solenoid of about twenty turns of heavy wire which extends between the outer armatures of the condensers (Fig. 338).

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[1] Rochfort, Annales d'electrobiologie, February, 1906.

Autoconduction Cage.—This form of high-frequency application is the typical d'Arsonvalization. The spark-gap is between the internal armatures of the condensers (Fig. 339), and the patient sits or stands inside a large solenoid or coil of wire, which is connected with the outer armatures. The patient is not in contact with any part of the apparatus.

Autoconduction by Double Guilleminot Spirals.—Guilleminot's technic places the two spirals so that they are parallel and in the same direction (Fig. 340). Starting from the external armature of one condenser the discharge passes to the external extremity of one Guilleminot spiral, then through fifteen turns of the latter, then through a conducting cord to the outer extremity of the other spiral, then through fifteen turns of the latter, and then through a conducting cord to the external armature of the other Leyden jar. It is important that the two spirals should be turned in the same direction. They are placed with their flat surfaces parallel with each other and 24 inches apart. With a powerful induction-coil or transformer and good condensers and spark-gap the space between the two parallel spirals becomes a very strong electromagnetic field. A single turn of wire, hanging freely in this space and parallel with the external turns of the spirals, will be traversed by a current which will light up a series of 12- or 20-volt incandescent lamps.

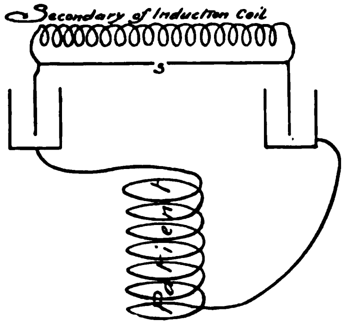

Fig. 339.—Autoconduction from d'Arsonval's large solenoid.

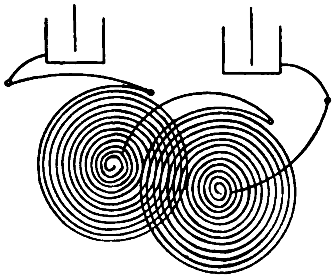

Fig. 340.—Guilleminot's technic for autoconduction.

There is no spark or effluve effect from the inner extremity of each spiral with the connections made in this manner.

For treatment the patient's body should be so placed between the two spirals that the long axis of the body is parallel with the external turns of both spirals. The simplest way is for the patient to sit with a spiral at either side of him and with his legs raised by some kind of a foot-rest.

Autoconduction by Guilleminot Spirals in Arterial Hypertension.—The treatments last twenty or thirty minutes, and in 15 cases reported by Guilleminot[1] the result of a course of treatments was to reduce the blood-pressure from about 21 cm. of mercury to about 17 cm. Fifteen or twenty treatments sufficed to produce a permanent effect, and after the first six treatments any general symptoms, such as vertigo, debility, dyspnea, chilly feelings, were greatly relieved.

Autocondensation.—Wires from two different turns of the small solenoid uniting the two outer armatures pass, one to an electrode held

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[1] Arch. d'electricité med., September 10, 1906.

by the patient and the other to a large sheet of metal upon which the patient lies, but from which he is separated by an insulating mattress (Fig. 341).

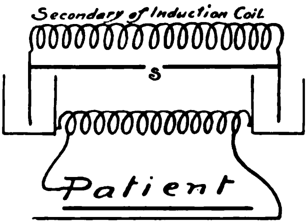

Fig. 341.—Autocondensation.

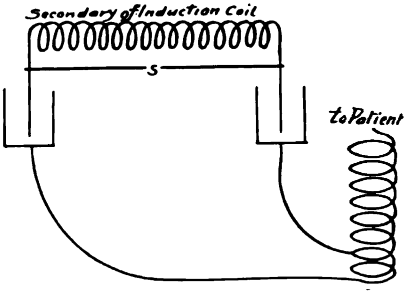

Fig. 342.—Oudin resonator.

Currents of High Frequency and High Tension.—*Oudin Resonator.* —In this apparatus the discharge from the outer armatures of the two condensers passes through a certain number of the lower turns in a helix of large wire, and by inductoresonance induces a very high-tension discharge from the other upper extremity of the solenoid (Fig. 342).

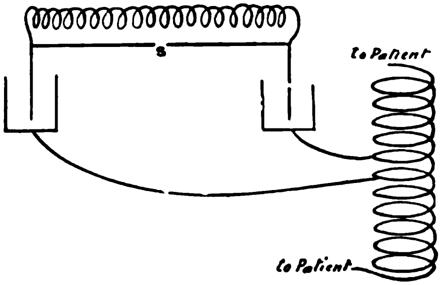

Fig. 343.—Bipolar resonator (O'Farrel and Lebailly).

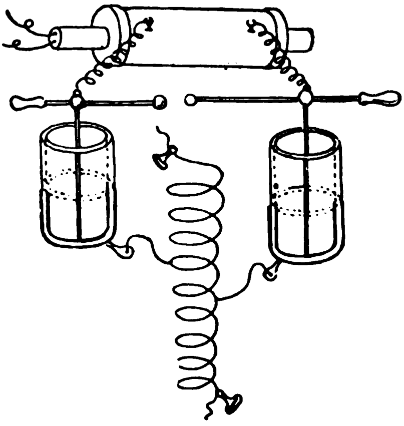

Fig. 344.—The apparatus of O'Farrel and Lebailly.

A Bipolar Oudin Resonator.—The wires from the external armatures of the condensers are connected with two of the turns near the middle of the helix, and a high-frequency and high-tension discharge takes place from both extremities of the helix (Figs. 343 and 344).

Guilleminot's Spiral.—The wires from the external armatures of the condensers are connected, one with the outer extremity and the other with one of the two or three outer turns of a flat spiral. A high-frequency high-tension discharge takes place from the inner extremity of the spiral (Fig. 345).

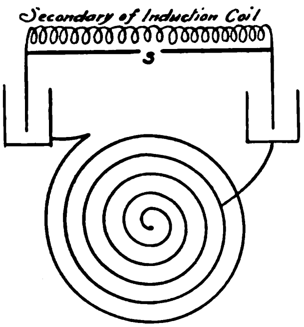

Fig. 345.—Guilleminot spiral.

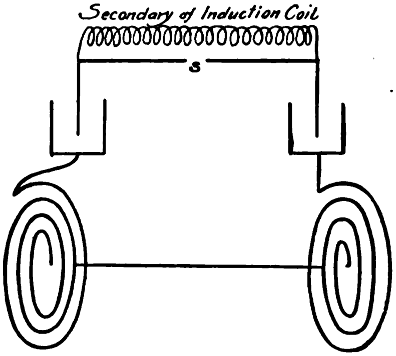

Fig. 346.—Bipolar spirals. Similar to the Rochefort apparatus.

Bipolar Spirals (*Rochefort's Principle*).—The connections are from the outer armature of one condenser to the outer extremity of one spiral, through the outer two or three turns of the latter, and through a separate wire to a corresponding turn of the other spiral, following this to its outer extremity and to the outer armature of the other condenser (Figs. 346, 347, and 348).

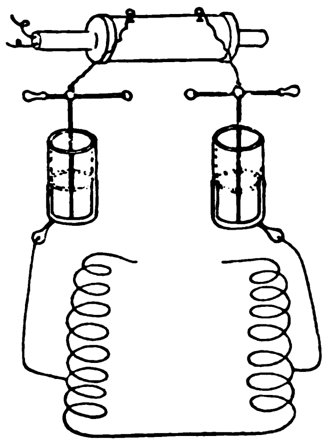

Fig. 347.—The Rochefort resonator for use with two condensers.

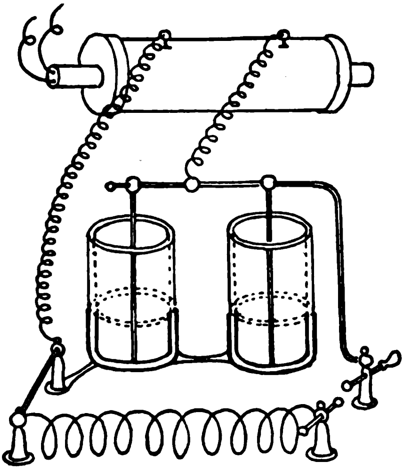

Fig. 348.—The Texeira transformer.

Hand Resonator.—This is also called an oscillator. It is an electrode handle which is in itself a high-frequency resonator (Fig. 349).

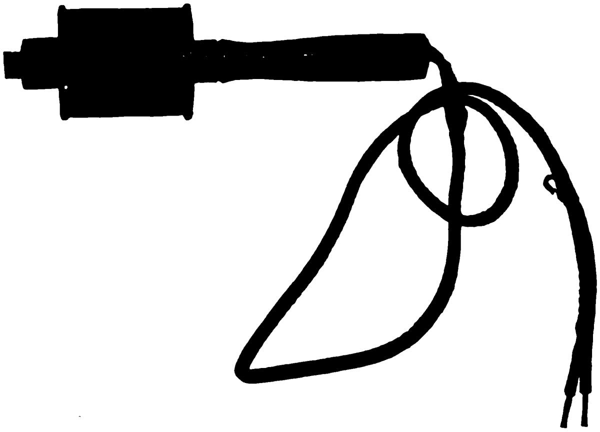

Fig 349.—Hand resonator or "oscillator" (Brown, Salem, Mass.).

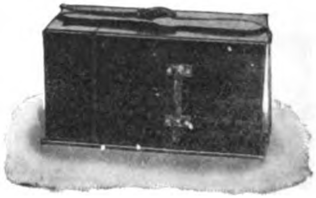

Fig. 350.—Portable high-frequency outfit (Browne).

A good effluve is supplied by such an apparatus when connected with an induction-coil and condensers.

The portable high-frequency apparatus sold for high-frequency and x-ray work (Fig. 350) is usually a Tesla outfit.

Another portable high-frequency coil (Fig. 351) is of such a size and weight that it may hang from any electric-light socket. It gives a sufficiently powerful effect for the spark treatment of moles and small epitheliomata and for the vacuum electrode treatment of neuralgia.

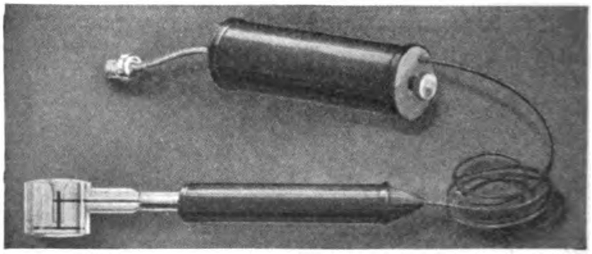

Fig. 351.—Remco high-frequency generator.

METHODS OF APPLYING HIGH-FREQUENCY CURRENTS

(*Machado's Table*)

- Methods of Unifrequence.
  - General application.
    - Autoconduction or inductive application at a distance without resonator, with d'Arsonval or Tesla-Thomson current passing through a large solenoid surrounding the patient.
    - Autocondensation (bipolar condensation).
      - Condenser couch. Schittenhelm couch.
      - Piffard's condenser mattress with metal spiral.
      - Glass condenser electrodes (Friedländer chair).
  - Local monopolar applications.
    - Without resonator.
      - With condenser.
      - Without condenser.
    - With resonator.
      - Electrode at a distance from the body.
        - Sparks
          - Direct application
            - Metallic applicator.
              - Ordinary
                - Direct discharge.
                - Indirect discharge.
              - Special for fulguration.
          - Indirect application.
            - Glass applicator.
              - Vacuum tubes.[1]
              - Tubes for cataphoresis.
        - Effluve.
      - Electrode applied directly to the skin.
        - Electrode stationary.
          - Ordinary metallic electrodes.
            - Direct discharge.
            - Indirect discharge.
          - Glass vacuum tubes.
            - Direct discharge.
            - Indirect discharge.
        - Electrode in motion.
          - Ordinary metallic electrodes.
          - Glass vacuum electrodes.
        - With Piffard transresonator.
        - Producing the high-frequency cautery arc.
      - Special glass vacuum electrodes applied to mucous membranes.
  - Local bipolar applications.
    - Without resonator.
    - With resonator.
      - One electrode on the skin and the other over exciter operating at a distance.
        - Sparks by means of:
          - Ordinary metal exciters.
          - Glass tubes:
            - Containing air.
            - Containing salt solution.
            - Tesla vacuum tubes.
        - Stationary effluve.
        - Rhythmical mobile effluve.
      - One electrode on the skin, the other discharging sparks against a metal also in contact with the skin (mediate discharge analogous to static wave currents).
      - Both electrodes at a distance from the skin (double effluve).
      - One metallic electrode applied to the skin, the other a glass vacuum electrode also applied to the skin.
      - Special glass vacuum electrodes applied directly to the surface.
      - One electrode from the Tesla-Thomson coil is applied directly to the skin, while another applies sparks to a metal ball held near another part of the skin (indirect sparks).
      - One electrode represented by Piffard's transresonator is applied to the skin, while the electrode from the other terminal of Piffard's hyperstatic transformer is applied to another part of the skin.

[1] There are:

- Glass vacuum electrodes.
  - With insulated handles.
    - With interior metal conductor.
    - Without interior metal conductor.
  - Insulated throughout their extent, except the active part for the urethra, rectum, vagina, mouth, etc.

Degrees of vacuum:
1/500 atmosphere — red vacuum.
1/10,000 atmosphere — white vacuum.
1/100,000 atmosphere.

METHODS OF APPLYING HIGH-FREQUENCY CURRENTS (*Continued*).

Mixed method. Autocondensation and effluve.

With special apparatus for electrothermopenetration, transthermie, electrocoagulation (Nagelschmidt, Lorenz, Reiniger thermoflex, Gaiffe, Doyen, etc.).

Methods of multifrequence.[1]	General application.	Undulatory high-frequency current by effluve interruption.
	Local applications.	Undulatory high-frequency current by arc interruption (pseudofaradic). Undulatory high-frequency current by spark interruption (called also motor-impulse current).[2]

VACUUM ELECTRODES WITH INSULATED STEMS

A glass vacuum electrode which is to be used in the rectum or mouth is often made with a double stem, the outer one being to protect the lips or the anus from sparks when a high-voltage application is made (Fig. 352).

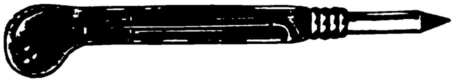

Fig. 352.—New improved insulated high-frequency tube.

The Author's Special Electrodes and Handle.—The electrodes used by the author, and perhaps original with him, have leading-in wires passing through the glass of the stem and making contact with a metallic part of the handle into which they are screwed, and by means of which the current is transmitted to them (Fig. 353).

The author's handle (Fig. 354) is made of hard rubber, insulating all the metallic portions from accidental contact with the patient, no matter what part of the handle may touch him.

The conducting-cord is the flexible insulated secondary conducting-cord used in automobiles. It depends upon cloth and resin or wax instead of rubber for its insulating properties. Soft rubber disintegrates in a few minutes under the influence of a high-tension high-frequency current. The proper conducting-cord can be touched by the operator or patient without any shock, only a shower of violet brush discharge like that from a condenser electrode. But if this cord is brought near any other cord conducting high-voltage electricity, a spark may perforate the insulation and leave a spot which is no longer insulated, and where if the cord be held for a few seconds a burn will be received from a continuous stream of white sparks. Such a burn is peculiar in causing pain for only a few seconds: it leaves a dry portion of dead epidermis which comes off like a scab, leaving a perfectly healed place underneath.

Application of High-frequency Current Vacuum Electrodes Through the Clothing.—Contrary to the conditions obtaining when

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[1] The combined effect of a wave of low frequency upon a current of high frequency.

[2] The effects are similar to those of Snow's static wave current to which are added the effects of high-frequency currents. The "motor-impulse current" produces contractions less painful than those produced by the static wave currents.

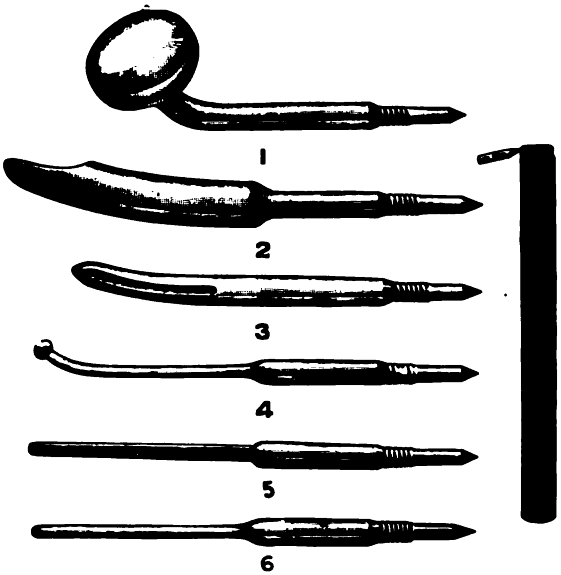

Fig. 353.—Author's vacuum electrodes with leading-in wires. Figure does not show the completely insulated handle.

Fig. 354.—Application of vacuum electrode by means of the author's completely insulated handle.

galvanic or faradic applications are made, high-frequency current and other glass vacuum electrode applications are not materially affected by the presence of a single very thin layer of silk, cotton, linen, or woolen clothing. Increasing the thickness of the material markedly changes the character of the discharge. A thicker layer of material, such as the underwear and trousers, changes the character of the application entirely. The adjustment of apparatus which will give a mild discharge without spark effect, but with the bulb filled with brilliant light when the bulb is directly in contact with the skin, shows practically no luminosity when applied through thick clothes. No beneficial discharge occurs through the clothes in this case. To obtain luminosity and a therapeutic effect it is necessary to adjust the strength of the primary current, the length of the spark-gap, and the other factors so as to produce a stronger discharge. There is a great deal more sensation because of the spark effect, due to the distance between the electrode and the surface of body and because of the stronger currents employed. A tube that is brilliantly illuminated produces a sharp burning sensation if applied through the trousers and held at one place for a short time. It should usually be kept in constant motion, and then produces no undesirable effect, the skin not being reddened unless the current is applied to a small region for an appreciable length of time. The author has never seen any injury to the clothing.

The effects of the application of a vacuum electrode through the thinnest underclothing are practically the same as if applied to the skin. There is the advantage of modesty in some cases, and no powder is required to enable the electrode to glide readily over the surface. The therapeutic uses are the same as those of the direct application to the skin.

The effects of an application through thick clothing are actively counterirritant and rubefacient if the electrode is kept in one place for an appreciable length of time and if the current is quite a strong one. They are revulsive without rubefaction if the current is less powerful and the electrode is kept in constant motion. The therapeutic uses are found in cases of chronic articular or muscular or nerve lesions where a powerful counterirritant effect is desired, and in some cases of neurasthenia, applied along the spine. The general indications for high-tension high-frequency currents are met by this application in cases where a very marked local effect is permissible.

Physiologic Effects of High-frequency Sparks and Effluves.—The effluve from a resonator applied from points 4 to 10 inches from the surface feels like a fine cool or luke-warm breeze, and this produces analgesia and sedation. From a nearer point there is a prickling, contraction of the cutaneous muscular fibers, redness, and arterial hyperemia. Nearer still there are powerful muscular contractions, both at the active effluve electrode and also at the indifferent contact electrode from the other pole of the resonator, but there is practically no heat generated in the tissues. Actual sparks applied in one place stimulate the cutaneous muscular fibers (goose flesh) and vasoconstrictors. After paleness, lasting one-half to one minute, an intense erythema develops. Prolonged application is followed by vasodilatation, edema, blistering, diapedesis of red cells. The longer high-tension sparks cause contraction of deep-seated muscles.

Electrolytic Effect of High-frequency Sparks.—High-frequency currents in general do not affect a solution of iodid of potash, but high-frequency sparks produce tiny blue points upon the surface. Nagelschmidt does not suppose that there is any important electrolytic effect upon the tissues from either the direct or the indirect high-frequency spark.

Fulguration, or Keating Hart's Method of High-frequency Sparks for Cancer.[1]—This method consists in the application of long and powerful sparks for the destruction of morbid tissue. The apparatus may be any of the resonators giving high-frequency currents, and may be either monopolar or bipolar, the latter being preferable. The patient holds a metallic electrode connected with one pole of the resonator, while the spark electrode is brought near the diseased area. This electrode has an insulating sleeve, by which the length of the spark is exactly regulated, and a current of air or CO_2 is forced through it to keep the temperature from becoming too high. The strongest possible discharges are used.

In the case of a small ulcerated epithelioma the application is divided into four different steps. At first several sparks are applied, producing blanching of the tissues and a marked degree of anesthesia, then more powerful sparks are applied, softening the tissues; third, the tissues treated by the sparks are curretted and enucleated; fourth, the same powerful sparks are applied at the bottom of the wound to eliminate any traces of neoplasm.

Larger tumors, especially those in which ulceration has not taken place, require the surgical procedure first, followed by the high-frequency sparks over the floor of the wound. The treatment requires a general anesthetic, and in some cases it is preferable to destroy different parts of a large tumor at a number of different sittings.

A typical operation by this method consists in an excision of a cancerous breast and axillary glands, under general anesthesia, of course, and then the application of these long, loud sparks to the entire raw surface, except the under surface of the skin flaps, which would certainly become necrotic if subjected to this treatment. As each spark strikes the exposed muscle a bunch of muscular fibers may be seen to contract violently. De Keating Hart continues to apply these sparks for a number of minutes, until the entire surface changes from a raw red to a dry, brownish, cooked appearance. Ample provision is made for drainage when the wound is closed. The consequence is a tremendous oozing of serum and a wound affording a fruitful field for infection, against which the greatest precautions should be taken. The theory is that the fulguration has a tendency to prevent recurrence by its effect upon the remaining tissues. Of course it cannot prevent recurrences in the skin or along the cicatricial line, because it cannot be applied there.

Having seen the method applied by the brilliant originator, and considering the results reported, the author feels that he cannot recommend this method for cases of this character.

The claim is made that recurrences are very much less prevalent after this method than after simple surgical excision, and that the cicatrices are as good cosmetically as those following radiotherapy. High-frequency sparks seem to have a selective effect upon morbid

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[1] Archives d'electricité medicale, August 10, 1907.

tissue, and the line of cleavage between the tumor and the surrounding flesh becomes more marked. The enucleation is easier. The same method has been applied for local tuberculosis, lupus of the skin and of the nose, and has even been found useful in certain cases of chronic *x*-ray dermatitis.

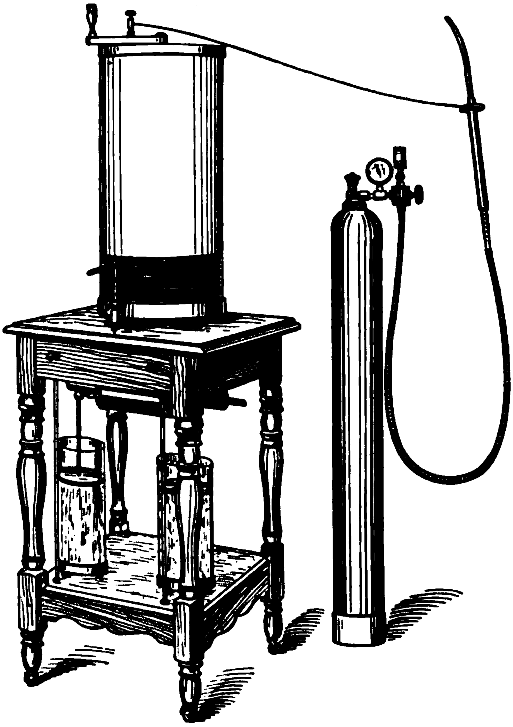

Fig. 355.—Keating Hart's apparatus for fulguration.

Many different electrotherapeutists employed high-frequency sparks before the publication of Keating Hart's method. The originality in the latter seems to lie in the combination of surgery and electricity.

The author's electrode (Fig. 357) for applying high-frequency sparks for their destructive effect was described at a meeting of the American Electrotherapeutic Association in 1905, and provides a means of regulating the strength of sparks from zero up to their maximum of length. The conducting-cord from the resonator is attached to the portion of the electrode which is to be applied to the patient.

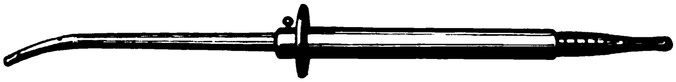

Fig. 356.—Keating Hart's electrode for fulguration.

This portion is separated by an insulated section from the portion which is held in the operator's hand. A lever actuated by a spring makes a connection between these two sections and conducts the entire discharge from the resonator into the operator's body. Pressing upon the lever introduces a greater or a less spark-gap between the two sections, and when the distance is at its maximum a powerful spark will pass to the patient. If anesthesia is not used, as in the case of small epitheliomata or warts, the author's technic consists of at first releasing the lever, then turning on the current, bringing the electrode near the part to be treated, and making an application of very small sparks, which are increased in length by pressing on the lever. When a certain degree of anesthesia has been produced, the sparks applied to the patient are gradually increased in length until they are about ½-inch long. The whole process takes but a few seconds from the time the application is begun until all of the current is being applied as a series of sparks. An application of ten or fifteen seconds is usually enough for the smallest neoplasm, and not more than a minute is required for those which are ½ inch or 1 inch in diameter. Intense inflammatory reaction, which follows the application, is usually the active factor in the destructive action, but in certain cases it seems desirable to apply sparks of special intensity and for such a length of time as actually to burn and char the tissues. The author's method gives good results in both ulcerated and non-ulcerated cutaneous epithelioma and in ulcerated carcinoma of the breast.

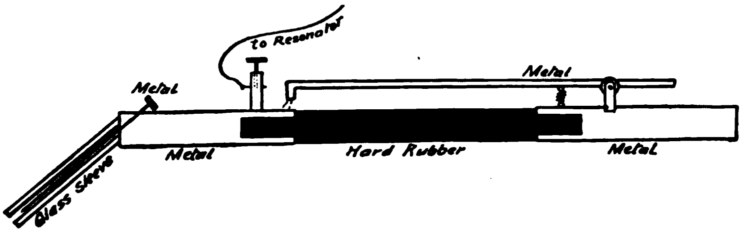

Fig. 357.—Tousey's electrode for high-frequency sparks.

Bipolar Oudin Resonator Applied for a Local Effect.—Oudin and Ronneaux[1] use two different adjustments for the application of high-frequency currents for local effect. Their apparatus consists of a bipolar Oudin resonator connected with two pairs of Leyden jars, charged by either a 50-cm. induction-coil or by a closed magnetic circuit step-up transformer actuated by an alternating current. One adjustment of the apparatus consists in connecting the diseased part with the upper extremity of one resonator while an effluve is applied by a brush electrode connected with the upper extremity of the other resonator. The other adjustment has the lower extremity of a single resonator connected with the diseased area, while the brush electrode is connected with the upper extremity of the same resonator. An improvement consists in placing the patient upon an insulated platform. The applications are made every two or three days. They last ten minutes, and are followed by a series of sparks lasting ten or fifteen seconds.

The *Crown effluver* (Fig. 358) has a range of usefulness similar to that of the static crown.

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[1] Le Radium, September 15, 1905, p. 302.

The Effect of Condenser Electrodes.—These electrodes consist of a metallic or other good conductor, covered by glass or hard rubber, acting as an insulating dielectric between the body and the conductor. A glass tube, shaped like a vacuum electrode and filled with salt solution, makes an excellent condenser electrode to be rubbed over the general surface or for introduction in the rectum. Such an electrode is applied to the surface and is connected with one pole of the d'Arsonval apparatus, while the patient holds a metallic electrode connected with the other pole. The effect is the same as when a glass vacuum electrode is used with the same kind of current. In the particular case described, and if the apparatus is adjusted for great amperage and low voltage, there will be little or no spark effect, and the local effect will be antiphlegmasic and sedative, while the constitutional effect will be to lower the blood-pressure if it is unnaturally high. There will be the same other less-marked effects that are obtained when a glass vacuum electrode is used. In no case does the salt solution in the condenser become luminous, and with the current regulated for a distinctly d'Arsonval effect there is only a little violet brush discharge where an imperfect contact is made with the skin.

A salt solution condenser electrode, with a higher voltage discharge, gives the same shower of sparks as the vacuum electrode, but much stronger with the same conditions in the rest of the apparatus.

This strong application produces a powerful revulsive effect, making it wonderfully effective in some cases of neuritis and myositis.

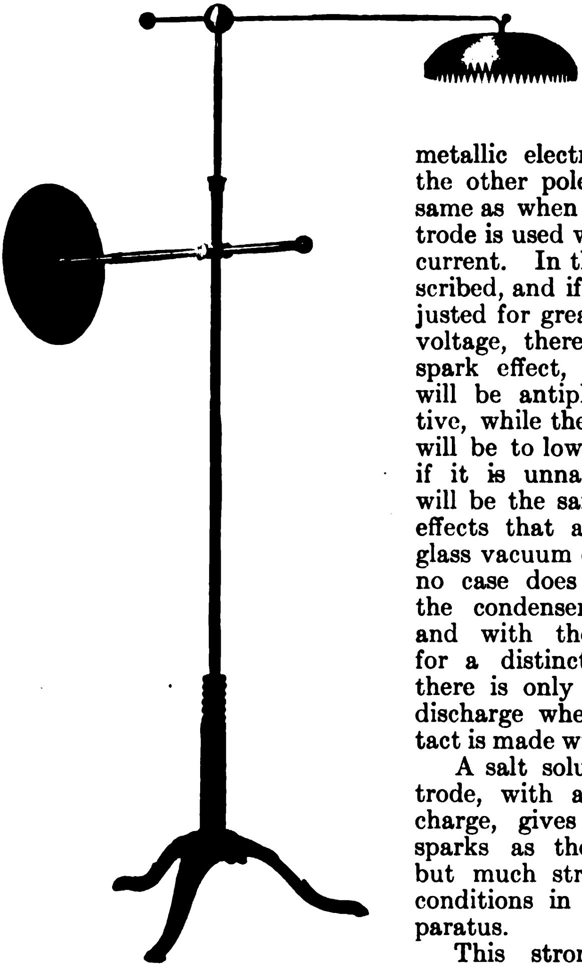


Fig. 358.—Crown effluver for high-frequency currents (Browne).

A salt solution condenser electrode is the most perfect means of making local applications for obtaining the different effects of the discharge either from a static machine, or from a Leyden jar connected with a static machine, or from either pole of an induction-coil (the strength to be limited by setting the spintremeter for a short spark), or of the discharge from a high-frequency apparatus of either the d'Arsonval or the Oudin type.

Condenser electrodes of metal with a covering of hard rubber produce effects similar to those from salt solution glass condenser electrodes, but are usually not intended to be rubbed over the surface of the body, but rather for introduction into the urethra or nose or for applications to the conjunctiva.

Condenser Electrodes of Large Size.—This is exactly what the autocondensation couch or pad amounts to. They are especially intended for use with the d'Arsonval or comparatively low-tension high-frequency currents, and except in the case of sciatica are generally used for the constitutional effects described in the section on Autocondensation.

OTHER APPLICATIONS WITH EFFECTS RESEMBLING THOSE OF HIGH-FREQUENCY CURRENTS

Glass Vacuum Electrode Connected with One Pole of a Tesla Transformer, Known also as a High-frequency Coil.—An easily portable outfit no larger than a handbag has been introduced in America (the Seeley *x*-ray apparatus and others), which consists of a complete Tesla apparatus. This requires only to be connected with an electric-light socket to be ready for bipolar use for exciting an *x*-ray bulb, or one pole only may be used to excite a vacuum electrode. The last application is the subject of the present paragraph. It has the same rather sharp spark effect which characterizes the similar use of an induction-coil, and the patient is liable to jump if any metallic object or another person touches him. It is, therefore, a less agreeable application than the one which employs a d'Arsonval or an Oudin apparatus to excite the vacuum electrode. A shower of sparks from it would be disagreeable. The therapeutic effects are similar to those from vacuum electrodes connected with the Oudin resonator. There is no muscular contraction and scarcely any sensation but that of warmth. There is a stimulation of metabolism and a tendency to raise arterial tension when it is abnormally low. It has analgesic properties.

Glass Vacuum Electrodes and the Static Machine.—The electrodes should have leading-in wires.

Their effect when connected with a high-frequency apparatus, either d'Arsonval or Oudin, actuated by a static machine, is about the same as when the high-frequency apparatus is actuated by an induction-coil.

Their effect when connected with one pole of the static machine without Leyden jars is somewhat different. The discharging rods of the static machine should be about ½ inch apart.

A series of shocks are felt when the electrode is held in the hand. It is as if slight muscular contractions were being caused, producing sensations in the different tendons in the wrist. If the electrode is lightly applied over the sensory nerves in the proximal portions of the fingers, a slight tingling sensation is felt at the distribution of these nerves. Rather sharp but very small sparks are felt when the electrode is held at a small distance from the surface. A greater separation of the conducting-rods produces more marked sensations of muscular contraction, which may extend up as far as the elbow. There is, however, no actual movement of the arm and no rigidity. The person is fully charged during this application, and any one touching his other hand, for instance, receives a sharp spark, which causes the hand to be drawn away. The therapeutic effect of the application is almost exactly the same as that of the Morton wave current.

Glass Vacuum Electrodes Connected with a Static Machine and Leyden Jar.—These give the same sensations as the application last described, and the same physiologic and therapeutic effects as the static induced current. The external armature of the Leyden jar connected with one pole of the static machine is grounded, while the glass vacuum electrode is connected with the external armature of the other Leyden jar.

These two methods of using the vacuum electrodes with a static machine are convenient means of local application of static electricity. Their effects are not due to the light in the tube, but to the nature of the current transmitted through the partial vacuum. The patient need not be insulated.

A Glass Vacuum Electrode Connected with One Pole of an Induction-coil.—A coil suitable for x-ray purposes may be used for this application. The vacuum electrode does not show much light until it is brought near the patient. Then quite sharp sparks pass to the surface, so that it is necessary to apply the electrode quickly, or in some cases, as in the rectum, to apply it before turning on the current. As the electrode is passed over the surface it is quite essential to constantly maintain a good contact with the skin, talcum powder enabling the electrode to glide smoothly over the surface. Every part of the patient is charged with electricity of such a kind that imperfect contact with any metallic object or another person will give rise to disagreeable shocks. A child sitting on its mother's lap while this application is being made usually cries most of the time because of the succession of shocks received from the mother. The induction-coil should be regulated to produce about a 2½-inch spark. The spintremeter should be set at 3 inches, so that the patient will be protected against the possible occurrence of an excessive discharge. The application causes no muscular contraction and no sensation except that of warmth when the electrode is in perfect contact and a moderate current is used. Such an electrode held in the hand while an excessive current is applied, the full power of an induction-coil, produces no muscular contraction in the sense of not being able to let go of the electrode or to move the arm in any direction. There are, however, the slight tingling sensations in the tendons about the wrist which most strong electric applications produce. There is nothing to be gained by making such an excessively strong application, but it does not affect the patient injuriously if done accidently or for experiment.

The effect of a glass vacuum electrode connected directly with one pole of an x-ray induction-coil is to produce a local counterirritant effect without the necessity for reddening the skin, and a general effect in the direction of increasing metabolism and stimulating the sympathetic nerves and glandular activity.

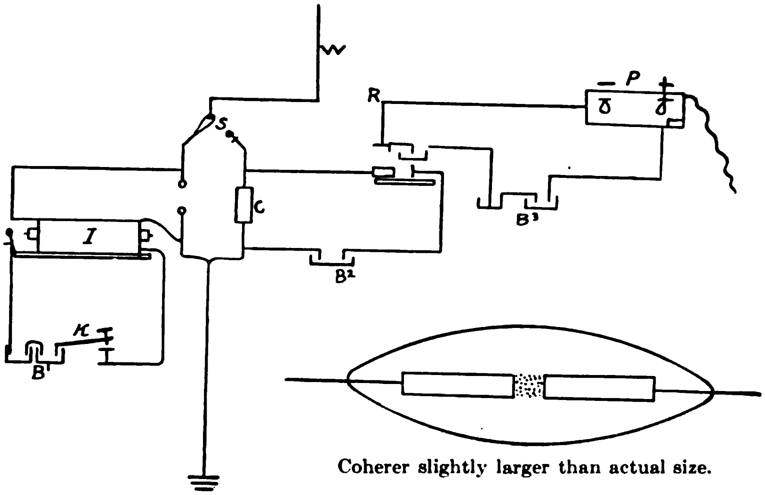
It is an excellent application for facial neuralgia, and mild cases (not tic douloureux) show improvement after the first treatment. Paralyzed muscles sometimes regain their size and tone in consequence of this application, as in cases of infantile paralysis treated by the author.

It will seldom be preferred to the Oudin or d'Arsonval currents with glass vacuum electrodes, and never for the application of a stream of sparks, because they are of a very disagreeable character.

Hertzian Waves.—These are electromagnetic waves propagated to enormous distances, and made use of in sending wireless messages for a distance of over a thousand miles. They are liberated by the discharge of an induction-coil and its condenser, and their commercial use is based upon the fact that they greatly lessen the resistance at an imperfect contact, and thereby act at each impulse to turn on a stronger current from the local battery which operates the telegraph receiving instrument.

These electromagnetic waves are generated in abundance by x-ray and high-frequency apparatus, and there is no doubt that they produce therapeutic effects.

The *Marconi wireless telegraphy sending and receiving station* is shown in Fig. 359. *S*, Switch to connect antenna with either sending or receiving outfit. In sending, every stroke of the interrupter charges W with a high electric pressure, which is relieved by the spark making a temporary path to the earth. Not only this but more charge rushes out of W than was put into it, and then electricity surges back again from the earth into W. A series of decreasing oscillations take place, like a bent spring coming to rest. Several million per second pass through wire and spark-gap. The visible sparks are twenty or thirty a second. Hertzian waves are set up, but recent work indicates that they do not transmit the message. Probably the currents rushing into and out of the earth tend to charge and discharge the earth itself and start radiating waves along the earth's surface. Receiving, the switch is turned the other way.



Coherer slightly larger than actual size.

Fig. 359.—Diagram of Marconi wireless telegraphy (Houston.)

C, coherer, two silver plugs with a pinch of metallic filings, tube exhausted and sealed to prevent oxidation.

B^2 affects a telegraph relay R only when resistance in C has been reduced by message.

B^3 is connected with the relay and a tape-printing telegraph receiving instrument *P*.

Waves in the earth encounter vertical wire, ascend it and influence coherer, causing its resistance to drop.

A buzzer is striking the coherer all the time, and causes the resistance to become great again as soon as the influence ceases.

Longest practical distance so far, 1500 miles.

THE PHYSIOLOGIC EFFECTS OF HIGH-FREQUENCY CURRENTS

Certain effects are common to all the different methods of application, and these are chiefly those of increased metabolism.

Other effects depend upon the mode of application and are chiefly vasomotor. Applications in which currents are induced in the human body have a general sedative effect upon the vasomotor system and reduce blood-pressure, while those applications which act more like static electricity, by sparks or effluve, have a stimulant effect upon the local circulation, and an effect upon the blood-pressure which probably slightly elevates it in health and tends to bring it to the normal when it is unnaturally low from disease.

Local Effects.—If a metallic electrode is in good contact with the skin or mucous membrane and the high-frequency current is of moderate strength—*i. e.*, 150 milliamperes or less—no sensation is produced until a sense of warmth gradually develops. This may change gradually to decided heat if the electrode remains in one place. With a greater strength of current, up to 400 or 500 milliamperes, metallic electrodes still give no other sensation than that of heat. If there were an imperfect contact, however, brilliant white sparks would pass from the electrode to the surface of the body, and this would produce a sense of pain and a reflex muscular contraction, drawing the affected part away from the electrode. With vacuum electrodes in good contact with the skin there is a little sensation of stimulation besides that of simple warmth. This is due to the very small sparks which form an invisible part of the discharge, even with a moderate current of 100 milliamperes, and with a heavy current of 250 milliamperes or more the outside of the bulb is covered with sparks passing to the surface of the body. In this case there is a sensation as of little sharp points striking the surface. The high-tension effluve produces a sensation as of a warm breeze, and if the effluve is brought too near the surface rather severe sparks leap to the skin and cause the usual sensation produced by an electric spark, but do not cause muscular contractions. The vacuum electrodes, held at a little distance from the skin, give rise to a shower of sparks which give only a sensation of warmth with very weak currents, but with moderately heavy currents the sparks are severe and painful, and if applied for any length of time in one place will cause blistering or necrosis. Electrodes of copper wire covered with hard rubber sometimes take the place of vacuum electrodes inside the nose and elsewhere. They give rise to a shower of very fine sparks, and produce at first a slight sense of irritation. Condenser electrodes with a wire surrounded by oil produce more or less sparking, and this resembles other high-frequency applications in the absence of muscular contraction.

The visible effect upon the skin varies according to the strength of the application. There may not be any noticeable effect or there may be redness lasting for minutes or hours, or groups of small red points looking like multiple pin-pricks. In some cases, as for warts, the current is used for a caustic effect. Generally speaking, a constitutional effect may be obtained from local applications without producing any visible local effect, and when a pronounced local effect is desired the application must usually be of such a nature as to produce some degree of visible effect. Repeated reactions from high-frequency applications will finally tan the skin, and sometimes, if too much spark effect has been employed, the skin becomes irritated. In this case treatment has to be suspended for a time.

The histologic effect upon the skin is stimulating, sometimes there is vasoconstriction followed by dilatation, and there is sometimes a degree of anesthesia produced. Ozone is produced upon the surface by the passage of electricity, and it is doubtless absorbed to a considerable extent. There is a vacuolization noted in microscopic preparations of the skin after the application of high-frequency currents which may be due to the liberation of oxygen or ozone in the tissues. The current has a tendency to promote the activity of tissue changes, and this is taken advantage of in the treatment of chronic inflammatory conditions. It is always observed that the glass electrode becomes covered with a dense dry coating of secretion from the surface of the skin, requiring the vigorous use of soap and water or even sapolio to remove it. This is due chiefly to the activity of the sweat glands under this treatment. The liberal use of talcum powder enables the electrode to slide readily over the skin and maintain a good contact; without it the electrode sticks to the damp skin and disagreeable sparking results as the electrode goes from place to place by jerks. The application, if at all thorough, is followed by a sense of warmth lasting from a few minutes to an hour. The odor of ozone or of nitrogen pentoxid may be detected upon the skin for hours afterward.

Spark discharges from a high-frequency electrode held at a short distance from the surface produce results similar to those of any other electric sparks. If severe and applied to one spot for more than an instant they cause a painful sensation and primary anemia followed by hyperemia of the skin. A prolonged application of severe sparks at one spot causes loss of hair and permanent destruction of some of the hair follicles. Wm. L. Clark[1] has given the name desiccation to the effect produced by a stream of high-frequency sparks applied to one spot for a few seconds. The tissue is cooked rather than burnt. Freund's experiment shows that such severe sparking produces an infiltration with polynuclear leukocytes in the rete Malpighii, extensive extravasation of blood, and vacuolization in the intima of the arterioles. The inner walls of the arterioles in the skin may be so much thickened by this gaseous infiltration as to fill the entire lumen. Similar changes are produced by the *x*-ray, by the ultraviolet ray, and by high-tension discharges of the same severity from static, faradic, or any other source.

Such spark discharges from a high-frequency apparatus have a very active bactericide effect, but this probably is not the case with applications of a suitable therapeutic strength. The beneficial effect from the latter is due to a vitalizing action upon the tissue cells with a consequent greater resistance to morbific organisms.

Moderate or severe high-frequency applications to mucous membranes, as about the mouth, eye, nose, rectum, or vagina, produce effects similar to those upon the skin. Applications of a therapeutic strength

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[1] Journal of Advanced Therapeutics, April, 1911, vol. xxix, No. 4, p. 169.

produce a vitalizing effect upon mucous membranes, not merely a transitory hyperemia or stimulation of secretion.

The Deeper Effect of Local High-frequency Applications.—Usually there is very little sensation and no muscular contraction. Where it is desirable to produce muscular contractions vibratory currents may be applied by connecting the vacuum electrode with one pole of the *x*-ray coil. No Leyden jars or solenoid or resonator are used. The electrode is passed rapidly over the abdominal wall, and if the current is fairly strong a very pretty play of muscular contractions is produced. These are entirely painless. With this application the patient has a high-potential charge, and will receive rather a disagreeable spark if another person or any good conductor touches him. The vacuum electrode must be kept in close contact with the skin to prevent disagreeable sparks. The strength of the secondary current from the *x*-ray coil should be sufficient to spark across a 3-inch gap, and the poles of the coil should be placed 3 inches apart if the limbs are being treated, or ½ inch apart if the current is to be applied to the gums or in the nose. The distance between the poles regulates the strength of the application in accordance with the sensitiveness of the part. The author has had especial success with this method in infantile paralysis, constipation, and chronic neuralgic affections.

Or, in another way of producing muscular contractions, the d'Arsonval transformer may be used and two metal electrodes applied to the patient, one of which he may hold. A short air-gap is made in the circuit with the patient and powerful painless muscular contractions are excited (F. F. Strong).

Local applications of high-frequency currents perhaps penetrate more deeply than other forms of electricity which are propagated to a great extent over the surface of the body. The deeper tissues share the heating effect of high-frequency currents. The activity of lymphatic and other glands is increased, and if the electrode is in the rectum the secretion of mucus in the rectum and bladder is increased. Therapeutically, this acts as an active stimulant in tuberculosis and other chronic inflammations. Sometimes this application excites a movement of the bowels some hours later. It always produces a tonic effect upon the entire nervous, vascular, muscular, and secretory structures of the bladder. The same effect is perceptible about the external genitals and vigorous erections are produced.

If applied through the clothes, underclothes, or bandages the discharge from glass vacuum electrodes has much more spark effect. This sometimes produces decided itching at the time of the application, but if the strength of the current has not been too great, and the clothing has been quite thin, this sensation quickly disappears. The current may be applied with good results even in the case of a limb all bandaged up for gouty eczema. Too long or too strong an application, or one continued too long without moving the vacuum electrode from one place to another, or with too much spark effect, will produce redness and itching of the skin which may be quite unpleasant.

A proper application produces some superficial anesthesia and diminishes the electric excitability of near-by muscles and nerves. With the temporary local hyperemia there is a consequent tonic effect upon the walls of the blood-vessels, which makes it a successful application in phlebitis and varicose veins.

High-frequency currents act upon chronic inflammation as a powerful eliminative or resolvent of infiltration and induration. Sometimes the effect of the x-ray and that of high-frequency currents upon the same case can be observed. The x-ray has an alterative, and high-frequency currents an eliminative, effect.

Like many other forms of electricity, high-frequency currents will experimentally kill bacteria or retard their development, but their therapeutic use depends very little upon any antibacterial property they may possess.

Applied over the abdomen high-frequency currents stimulate gastric and intestinal peristalsis.

Most of the general systemic effects may be produced by the application of vacuum electrodes over a considerable portion of the body, and, providing the current passing through the vacuum electrode is strong enough, it seems to make little difference whether the patient is holding a metallic electrode from the other pole of the d'Arsonval or whether it is entirely unipolar from the Oudin apparatus.

Effect of Local Applications of d'Arsonval Currents.—These may be made by *direct* metallic contact, as by metallic electrodes, from the two terminals of the small solenoid, and in that case the effects are the same as from the general application, with an additional local analgesic, resolvent, vasomotor, and trophic effect.

Indirect applications include those of sparks or effluve and those by vacuum and condenser electrodes. Their effect is both local and general. The *general effect* is partly the same as that from general applications, lowering arterial tension (except when glass vacuum electrodes are passed lightly up and down the spine with an adjustment of apparatus producing great spark effect) and stimulating metabolism and similar effects, but it has also an effect due to local congestion and a consequent reflex influence upon every organ in the body. It gives origin to a change in the chemic and physical state of the blood which affects the protoplasm of the red and white blood cells, whose exchanges become more rapid, and to changes in the blood-plasma.

Toxic or inflammatory products are more quickly eliminated.

The *local effect* of local indirect applications of d'Arsonval currents is important. It differs considerably according to the method of application. A glass vacuum electrode, making a good contact with the surface of the skin or with any of the mucous membranes, while a good contact is made with a metallic electrode from the other pole of the d'Arsonval apparatus, produces no sensation but that of warmth if a current of moderate strength is passing through the patient, 150 ma. for instance. But this seems to have a cumulative effect, and the vacuum electrode becomes uncomfortably hot after being used in the rectum for more than five minutes. Rubbed rapidly over the surface with powder to insure a good contact, a much stronger current may be used without discomfort from heat except in sensitive regions like the face. The glass becomes quite hot, however, and fatty material, derived from the skin and mixed with the powder employed, forms a white crust on the surface of the glass almost as hard as enamel and requiring soap and hot water to remove it. The skin becomes somewhat reddened from an application of a strong current of 200 ma. or more. The character of the application may be varied somewhat. The number of milliamperes may be increased without changing the voltage of the current through the patient by using a stronger current in the primary of the induction-coil. The voltage may be increased independently of the amperage by increasing the length of the spark-gap: this produces a greater spark effect from the glass vacuum electrode. The greater the amperage and the less the voltage the more purely d'Arsonval is the application, and the greater the voltage, with a corresponding reduction in the amperage, the more purely Oudin or high-frequency high-tension does the application from glass vacuum electrodes become.

The local effect of glass vacuum electrodes connected with the d'Arsonval apparatus and the current, so regulated as to produce warmth without spark effect (d'Arsonval character), is hyperemic; sedative of sensitive nerves, both near the surface and deeper seated; antiphlegmasic in all kinds of inflammation, acute or chronic, simple or infective; and trophic, stimulating the tissue cells to healthy activity and development.

The local effect of glass vacuum electrodes, connected with the d'Arsonval apparatus with the current adjusted so as to give the greatest spark effect and very little amperage, is the same as if it were connected with the Oudin resonator, but it will be described here for convenience. A small vacuum electrode, $\frac{1}{4}$ inch in diameter, held near one spot for a few seconds applies a shower of fine sparks, which anesthetizes the skin to such an extent that a more severe application does not cause pain, and even slight operations could be performed. Holding the glass electrode close to the skin or in contact with it the sparks are more severe, and presently the skin turns white, and a few minutes later a zone of intense redness forms around the white area. It takes only a minute's application at the same spot with the strongest discharge to cause local superficial destruction. The subsequent course is for a sort of pus blister to form, looking like a vaccination pustule. This gradually changes to a dry scab, which leaves no scar if the application has been comparatively mild, as for treating a wart, or quite a distinct scar if it has been severe, as for the destruction of an epithelioma. A larger vacuum electrode, which may be applied to a surface 1 or 2 inches in diameter, may be passed quickly over the surface without making very close contact, and produces with this high-tension discharge hyperemia of the surface and a counterirritant effect, and an effect upon painful nerves which may not be desirable in certain cases; it seems to "key them up." The skin may even be made somewhat red and rough by too frequently repeated applications with too great a spark effect. The application is a powerful resolvent and antiphlegmasic and usually relieves pain.

The Effect of the Violet and Ultraviolet Radiations from the Glass Vacuum Electrodes.—Visible light is produced by the passage of a current of electricity through a tube exhausted to about $\frac{1}{1000}$ atmosphere. The color varies with the exact degree of vacuum. Some of these tubes are filled with a beautiful blue, lilac, or violet color, and in some there are also patches of the apple-green color which indicates the presence of an appreciable amount of x-ray. The visible light from one of the vacuum electrodes has no demonstrable physiologic or therapeutic effect.

The passage of the current through the partial vacuum, and especially through the air between different parts of the tube and the patient (for minute sparks may be seen passing along the outside of the tube from parts not in contact with the patient), produces *ultraviolet radiations* sufficient to cause fluoroscence in a piece of Willemite held near the tube in a dark room. The ultraviolet ray thus produced has its usual properties of liberating ozone from the atmosphere, and of being absorbed by the most superficial layers of the skin. It is hardly to be supposed that the ultraviolet rays absorbed by the body during a treatment by means of vacuum electrodes takes any more direct part in the physiologic or therapeutic effect.

The ozone produced by the application of the vacuum electrodes and ultraviolet radiations is very important. Rubbing the vacuum electrode over perhaps a fourth of the surface of the body for ten or twelve minutes bathes the patient in ozone gas for that length of time. It is absorbed by the body just as carbonic acid gas is absorbed from bathing in water charged with that gas. Its general effect is that of ozone inhalations, increased processes of oxidation in the blood and every other tissue. Nitrogenous substances are completely oxidized and leave the system as urea instead of being incompletely oxidized to form uric acid, some of which would be eliminated, but some of which would form an irritant deposit in the joints or nerves. The odor which is noticed upon the patient, and which may even cling to his clothes for several hours, is chiefly that of nitrous acid produced at the same time as the ozone. This acid may play some part in the effect produced by the application. Vacuoles or cavities filled with ozone may be found in the tissues directly subjected to this treatment.

In addition to the effects described the glass vacuum-electrode application has other effects which are dependent upon the nature of the currents which it transmits. These may be either those of the low-tension high-frequency type, called d'Arsonval currents, or the high-tension high-frequency currents, of which the Oudin resonator yields an excellent example, or the current from a static machine, or the current produced by one pole of a Tesla coil. These are the types of current which are most often applied by means of the vacuum electrodes, and they have quite different effects, especially upon the general system.

Systemic Effects of High-frequency Currents.—*Experiments Showing the Effect of High-frequency Currents on Animals.*—D'Arsonval's experiments[1] showed in a general way that high-frequency currents caused the blood-vessels in a rabbit's ear to dilate at first and then to contract and remain so, also that the general blood-pressure was first reduced and then increased.

Carvallo[2] found no effect from the autoconduction cage, but that there was an effect from the application of the currents directly to the skin. Strong currents cause sensation and a motor reaction and a fall in blood-pressure.

Boedeker used the apparatus already described as the German arrangement. He found no effect from the autoconduction cage, but a decided effect from a direct application to the skin, a primary phase of vasomotor contraction and increased blood-pressure.

According to Doumer,[3] of Lille, France, the effect of high-frequency currents on the cells is the fundamental one, and this can be demonstrated on vegetable as well as animal cells.

Observations Upon the Effect of High-frequency Currents Applied

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[1] Arch. d'elect. med., 1897, p. 213.

[2] C. R. XIII, Internat. Med. Congress, Paris, 1900, section on Physics and Physiology, p. 120.

[3] Le Radium, Sept. 15, 1905, p. 302.

Locally in Man.—D'Arsonval's observation, that after a long or strong enough application the skin becomes reddened locally and local and general perspiration sets in, is a matter of daily observation by the author when using vacuum electrodes connected with the Oudin resonator. D'Arsonval finds that a change in arterial pressure is produced in certain diseases, such as diabetes, from a local action of electrodes held in the hands and connected with the small solenoid. Some patients show a material fall and others a material rise in blood-pressure.

Moutier found that sparks from an Oudin resonator applied along the spine produced a very rapid rise in blood-pressure, amounting to 4, 5, 6, 7, or even 8 cm. of mercury. These and static sparks along the spine are the best methods of treatment for neurasthenia with hypotension.

Doumer and Oudin find that high-frequency high-tension sparks turn the skin white, and that this is succeeded by an erythematous blush which may last for hours. The author has observed this especially in cases where high-frequency and high-potential sparks are applied from a metallic electrode, as for the destruction of epithelioma, but in these cases there is apt to be a central pure white area where the sparks have been applied, surrounded by a zone of intense redness.

According to Oudin's observations, an application of the high-frequency high-tension effluve to any portion of the body produces an almost instantaneous vasomotor spasm which suppresses the capillary pulse in the hand. When the application is stopped the capillary pulse gradually regains its original amplitude through a series of oscillations.

The monopolar effluve of high-frequency currents increases arterial tension[1].

THE EFFECT OF GENERAL APPLICATIONS OF HIGH-FREQUENCY CURRENTS

Effects of General d'Arsonvalization.—A current of 600 to 1000 ma. from direct metallic contact or by induction traverses the body, often without any sensation and always without pain. Equally strong currents from vacuum electrodes or spark electrodes or effluvers, or from condenser electrodes or autocondensation pads or couches acting as such, may give rise to sparks which are anesthetizing or painful or cauterizing or destructive, according to their size and the length of time during which they are applied to one spot. There is a sensation of warmth in the hands from holding the metal electrodes in autocondensation.

There are increased tissue changes, more rapid oxidation, more rapid reduction of the oxyhemoglobin in the blood, increased elimination of waste products in the urine. The effect is due to an action upon the great sympathetic nerves controlling vasomotor, secretory, thermogenetic, and peristaltic functions. The general applications have little or no effect upon the central nervous system controlling sensation and voluntary movement. It has special effects upon the protoplasm of tissue-cells everywhere, increasing the rapidity of their natural chemic changes, and special effects on bacteria and ferments and animal poisons.

There is a soothing effect upon any painful condition, and sometimes this may be accompanied by slight drowsiness. Sometimes, however,

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[1] Albert Weill, Le Radium, Sept. 15, 1905, p. 302.

there is a sense of exhilaration, and one patient of the author's felt like walking all the way home (twenty miles) after each treatment. More often, however, there is no immediate change in the way the patient feels.

The effect on the blood-pressure is of great importance, and like other forms of electricity, high-frequency currents act as regulators of this condition without producing a marked effect upon a healthy person. The same is true of the effect of digitalis upon the blood-pressure, according to the observations of Czyhlarg.[1] He found that when an infusion of digitalis is given to individuals with normal circulatory apparatus in quantities equal to that administered to persons with valvular disease, there is no increase in the blood-pressure or in the amount of urine excreted. In cases of rheumatism, gout, asthma, and kidney disease, and in neurasthenia with high arterial tension the application of high-frequency currents causes a reduction of the blood-pressure. The autoconduction cage has been found more effective in this way than the autocondensation couch or the application by vacuum electrodes, but any method will produce the desired effect. This reduction is progressive from one treatment to another and occurs even in cases of arteriosclerosis, for which high-frequency currents are an excellent treatment. The observations of Moutier and Challamel[2] show that a reduction of 5 to 9 centimeters of mercurial pressure takes place after the first treatment with the cage in cases of high arterial tension. Five centimeters is the maximum reduction from a single treatment with the couch.

In cases of defective metabolism we find increased oxidation produced by high-frequency currents. In gout and rheumatism the urine contains an increased amount of urea, while the uric acid disappears. In other words, the nitrogenous matter becomes more completely oxidized in the system. And this effect is not a temporary, but a permanent one of increased tissue activity. The energy is so great that it produces a tonic effect upon any person within 10 feet of the apparatus. The present author enjoyed extraordinarily vigorous health during the four or five years following the introduction of these currents, in spite of the fact that the nature of the work confined him to the office practically all day, winter and summer.

The oxygen-carrying capacity of the hemoglobin of the blood is increased as well as the amount of hemoglobin. The human output of carbon dioxid is sometimes increased from 17 to 37 liters per hour, and there may be an increase in heat production from 79 to 127 calories per hour. The bodily temperature does not vary more than a small fraction of a centigrade degree (d'Arsonval).

The amount of phosphoric acid in the urine is increased. The toxicity of the urine is increased. There is an increased elimination of CO_2.

The application is apparently innocuous, and there are no special contraindications, except that perhaps it is less likely to be of benefit in acute inflammatory conditions than elsewhere. And it is but fair to state the belief of some observers that it is likely to precipitate an acute attack of gout, though this appears very doubtful. The author has used it successfully in the treatment of acute attacks.

[1] Wiener klinische Rundsthau, April 15, 1900.

[2] Academie des Sciences, Paris, Feb. 13–23, 1905.

Sometimes an increase of arterial tension will be noticed in a healthy person in consequence of the application.

High-frequency currents produce a reduction in weight on account of the increased oxidation. This is most noticeable in cases of obesity.

The Thermal Effect of High-frequency Currents.—Somerville[1] has especially called attention to the increase in surface temperature and also in the temperature in the mouth which occurs during the application of high-frequency currents. This increase amounts to from ½ to 1° F., and has been verified by Lacomte, Benoist, d'Arsonval, Wertheim Salomonson, and others. Various explanations are offered: Somerville says "this rise of temperature is undoubtedly due to the action of high-frequency currents on the vasomotor system, which under the influence of the current permits of increased peripheral circulation."

There is a dilatation of the deeper vessels also. This undoubtedly explains why the sphygmometer pressure is lowered. Somerville shows also that the emission of heat from the body is increased. There is probably an increased production of heat, and this is accounted for by Salomonson on a purely physical basis.

These high-frequency currents of high voltage and amperage can heat the filaments of electric lamps through which they pass to incandescence, and it is evident that they produce a certain thermic effect in passing through a conductor as resistant as the human body. Wertheim Salomonson regards this as offering a sufficient explanation of the rise of temperature which is observed.

He thinks that the diminution of arterial tension and a part of the general curative effects of high-frequency currents depends upon this production of heat in the body either locally or generally. These observations apply to bipolar applications from electrodes directly in contact with the body, to the condenser couch, and to monopolar applications with the Oudin resonator. He does not think that they apply to the action of the effluve or of the condenser electrode.

Observations Upon the Effect of High-frequency Currents in Patients with High Arterial Tension.—The apparatus used in many of Moutier's cases was a 9-inch induction-coil with a mechanic interrupter, a Gaiffe plate condenser with petroleum oil insulation, and an autoconduction cage. At the first treatment the blood-pressure was lowered 3, 4, 5, 6, or even 9 cm. of mercury, and in a few treatments the blood-pressure was always reduced to normal, about 15 cm., where it would remain for several weeks.

Challamel has found that the pressure may even be reduced to subnormal, 11 cm.

Gay has obtained the same beneficial results from the use of the autoconduction cage in cases of neurasthenia with high arterial tension.

Gidon in 5 cases not subjected to any dietary regimen; Doumer and Maes in a case of Parkinson's disease and Legendre in a case of cryesthesia, and many other French authors have obtained the same reduction in arterial tension.

Boedeker and other German authors have not obtained the same results. Generally, in fact, there has been an increase in arterial tension, which was very marked in some cases and averaged 5 cm of mercury. This increased blood-pressure disappears after about twelve minutes.

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[1] Medical Electrology and Radiology, May, 1906.

The difference in the results may be due to difference in the apparatus, as explained on p. 532.

Further Details of the Application of High-frequency Currents in Hypertension.—Short treatments of not more than five or ten minutes are best, and should be given two or three times a week.

Diuretics and laxatives are desirable to avoid the effect of increased metabolism at the beginning of the course of treatment.

Apostoli found that the autoconduction cage is contraindicated for certain classes of diseases—hysteric anemia, debility, senile rheumatism, and certain cases of diabetes, anemia, and chloro-anemia. Some of these patients experience nausea or vertigo and depression.

Denoyès found that many patients with different diseases experience no sensation, while others notice a prickling sensation or that the face feels hot, and others feel a little vertigo or sense of slight intoxication after the treatment.

Moutier notices that patients with low arterial tension feel badly if treated by the autoconduction cage, and consequently patients with lithiasis and hypotension requiring high-frequency treatment should receive this in the form of sparks applied along the spine. This tends to raise the blood-pressure.

Patients with hypertension treated by the autoconduction cage sometimes notice slight formication, sometimes a decided feeling of well-being, but generally no sensation at all.

The pulse rate is but slightly affected.

The enlarged heart in old cases of hypertension becomes smaller.

Cases in the hospital and on a strict diet of bread and milk often have a normal arterial tension after three treatments in the autoconduction cage. The rapidity of the results is usually proportional, not to the severity or the duration of the disease, but to the hygiene of the patients. The results are equally good in cases where a strict diet without high-frequency treatment has proved unavailing.

Experiments have been reported by Josué, Loeper, and Josserand upon animals whose arteries have been made atheromatous by long-continued high arterial tension from repeated injections of adrenalin. High arterial tension seems to be the cause of the arteriosclerosis which follows.

Autoconduction of high-frequency currents affords the best means of treating arteriosclerosis by removing its cause, high arterial tension.

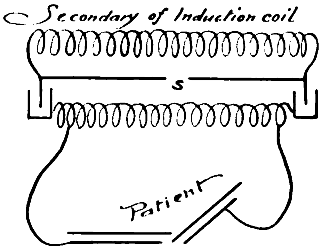

Fig. 360.—d'Arsonval high-frequency currents applied by autocondensation pads.

Effect of Applications of High-frequency Currents in Arterial Hypertension.—The author's customary method is by the use of an autocondensation pad (Fig. 360). The spark-gap is between the inner armatures of the two condensers, which are also connected with the secondary terminals of a 12-inch induction-coil. A small solenoid connects the outer armatures, and from two turns of this solenoid wires pass to two separate sheets of metal, one placed on the seat and the other on the back of a chair. Sheets of heavy indurated fiber insulate the patient from the metal. A milliamperemeter shows the strength of the current in one of the wires leading to this pad to be perhaps 700 ma. when the patient is seated upon the pad, and only 100 ma. when he is not. This would apparently indicate that 600 ma. of high-frequency current traverses the patient's body.

The treatments last five or ten minutes. They have not in the author's cases been followed by the very marked fall in blood-pressure reported by Moutier from the autoconduction cage, but by a more gradual improvement in consequence of a course of treatments. Patients with arteriosclerosis resulting even in hemianopsia and other apoplectic effects have been restored to apparent health.

Delherm and Laquerriere,[1] after considerable experience with the effects of the autocondensation couch and the autoconduction cage, and following as closely as possible the technic employed by Moutier, have come to the following conclusions: (1) That the immediate reduction in blood-pressure is not as constant or as marked as others have observed it to be. (2) The permanent reduction is decidedly less marked and less constant. (3) Even with a suitable regimen high-frequency currents do not surely prevent the bad effects of arteriosclerosis. (4) There does not seem to be a marked reduction in capillary blood-pressure, but there is a decided increase in the amplitude of the capillary pulse. (5) The best clinical results in high arterial tension are apparent in patients who can be classed under the general heading of congestion (arthritic, gouty, arteriosclerotic, etc.). (6) Benefit does not alone depend upon an effect on the blood-pressure, but perhaps more upon an effect on general nutrition and the urinary elimination. The modification in the capillary pulse produces a better aëration in the lungs, a more marked elimination of carbonic acid, and a more active fixation of oxygen by the blood. This increases the rapidity of the exchanges and the activity of thermogenesis. Toxins are more completely eliminated.

Doumer's Results with a Measured Electromagnetic Field in the Autoconduction Cage.—Believing that differences in clinical results may follow differences in the strength of the field in which the patient is placed, he regulates his apparatus so as to produce in every case a field of 506,000 Gauss. (Moutier's field averages 400,000 Gauss.) The meter for this observation is placed in view inside the autoconduction cage. The necessity for such a meter lies in the fact that the strength of the field varies with different apparatus, and even with the same apparatus if the interrupter or the spark-gap acts a little differently. He uses a 12-inch induction-coil as the source of his power and plate condensers immersed in oil.

All four patients reported upon[2] showed a steady improvement from a blood-pressure of 27, 26.5, 29.75, and 26 mm. of mercury respectively to 13.5, 16, 17.75, and 16 mm. The treatment lasted ten minutes, and was given daily, and from three to fifteen treatments were required. The blood-pressure remained normal after the treatments were discontinued. One patient had a large hydrocele, which disappeared during the course of treatment without any direct applications or local treatment at all.

Some observers have found that the same currents applied in cases of hypotension increase the arterial tension, but the higher tension applications from the Oudin resonator are more effective in this direction.

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[1] Arch. d'Electricité Med., July 10, 1907.

[2] Ibid., July 25, 1906, p. 556.

The effect upon the blood-pressure is not due to a depressing effect upon the heart. The d'Arsonval applications relieve the heart from the strain encountered in driving blood through the contracted arterioles and capillaries, and the Oudin applications have a tonic effect upon the heart as well as upon the vasomotor system.

Effect of High-frequency Currents in Diabetes.—D'Arsonval and Charrin, Boinet and Poncy,[1] Apostoli and Berlioz, Reale and Renzi, and Vinas have treated numerous cases of diabetes by approximately the technic to be described. The secondary terminals of an induction-coil are connected with the internal armatures of two condensers and the spark-gap is between the latter. The outer armatures are connected by a small solenoid, from two turns of which wires lead, one to a metal electrode held in the patient's hand and the other to a foot-plate or foot-bath making contact with the patient's foot (Fig. 361.

Every one of the authors cited report uniformly beneficial effects upon the patient's general condition, whether the sugar disappears from the urine or not. In most cases the sugar was markedly reduced in amount and in several cases it entirely disappeared. The treatments usually lasted ten minutes, and were given every day for ten or twenty days.

Autoconduction cage treatment did not lead to a disappearance of the sugar in four cases reported by Vinaj and Viette.

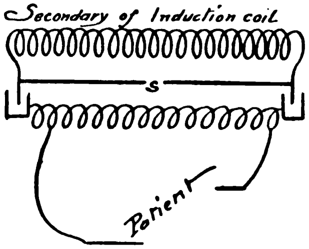

Fig. 361.—D'Arsonval high-frequency currents applied by two electrodes for diabetes.

Cohn also finds that high-frequency applications do not modify the amount of sugar.

Boedeker, using an apparatus with the spark-gap between the external armatures, the German method (Fig. 337, p. 532), found that high-frequency currents did not change the amount of sugar, but did very markedly improve the general health. In one case of diabetes there was marked acetonuria, which completely disappeared during a course of high-frequency treatments, but returned after the treatments were stopped.

Denoyès has obtained excellent results as to general health in cases treated by the autoconduction cage, but the circumstances of the patients as to diet, etc., were such that the effect upon the sugar could not be determined.

Cases of diabetes treated by the author have shown a reduction in the amount of sugar from 2700 grains (180 grams) per diem to a mere trace, and this has been associated with a very great improvement in general health. The treatment has been by the application of a glass vacuum electrode over the abdomen, the current being a unipolar high-frequency high-tension discharge from the Oudin resonator (Fig. 362). Applications of the *x*-ray have been made over the region of the pancreas and liver.

Other Effects of High-frequency Currents.—Capillary vasoconstriction is most marked when the high-frequency high-tension effluve or sparks are applied to a part of the body symmetric with that in which the capillary pulse is studied.

The lowering of blood-pressure produced by d'Arsonvalization is

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[1] Memoires de la Societe de biologie, July 31, 1897.

followed by a rise which lasts for a considerable time, just as the contraction of the capillaries from the Oudin application is succeeded by a period of capillary dilatation which may even be permanent.

Cases in which high-frequency high-tension applications, such as effluviation along the spine, appear to be indicated should not receive this application if the blood-pressure is 16 cm. of mercury or higher than this.

High-frequency Currents in the Treatment of Tuberculosis.—This subject is partly considered in the paragraph on Pulmonary Tuberculosis (p. 586). The technic for such cases is given in detail there. The beneficial effect in general or local tuberculosis seems to be due, not to any direct effect upon the bacilli, but to a tonic effect upon the tissue cells and upon all processes of metabolism. The results of high-frequency treatment, especially when combined with the *x*-ray, have been excellent.

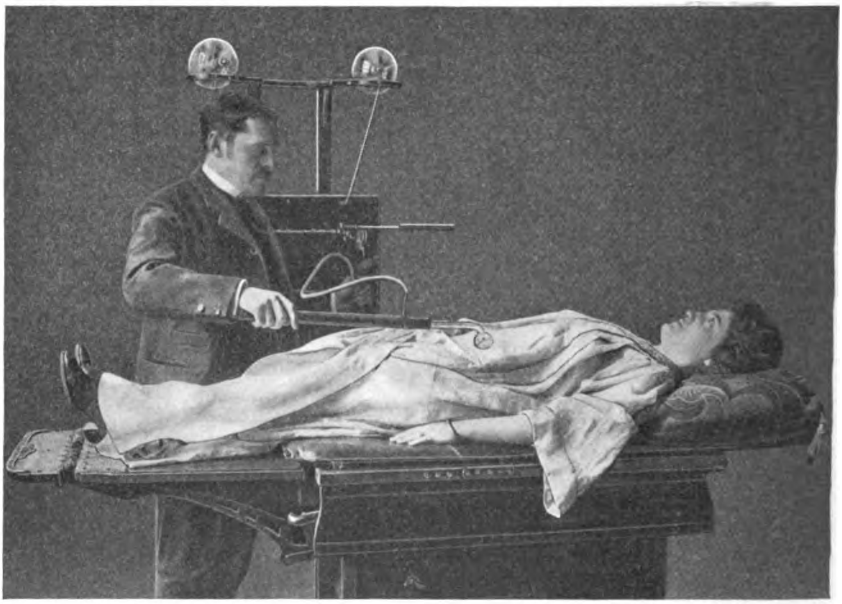

Fig. 362—Application of high-frequency current for diabetes. Glass vacuum electrode from Oudin resonator.

The current employed in the following case treated by the author was not a high-frequency but a vibratory current, having a similar therapeutic effect in this class of cases. The patient was an old woman at St. Bartholomew's Clinic, who had undergone an operation for extensive tuberculosis of the dorsal vertebræ seven months previously. A discharging sinus still remained, and through it the probe found an extensive area of softened bone. The treatment consisted in the application of about one Holzknecht unit of rays No. 5 Benoist from an *x*-ray tube placed at a distance of 10 inches from the anticathode to the skin twice a week. On the same days, and also on one other day each week, a vacuum electrode connected with one pole of the *x*-ray coil was applied all over the affected area for about ten minutes. The spintremeter of the coil was set so that any secondary current in excess of that required to produce a 3-inch spark would pass across the gap between the poles of the coil. This acted as a safety-valve to prevent an undesirably strong current from passing through the vacuum electrode to the patient. The Oudin resonator would have been a better source of high-frequency currents for this case, but was not available. With the Oudin or the d'Arsonval the current should be almost 200 ma.; the electrode should be kept in motion and the application last about ten minutes. The result in this case was permanent closure of the sinus in about three weeks. The possibility of an effect upon the spinal cord of course had to be considered in determining whether to use the *x*-ray in this case, and it certainly would not have been wise to continue its use for any great period of time. In such conditions of the bones it seems as if the beneficial effect was in the nature of an increased action by the tissues, resulting in the molecular removal of the diseased parts, and healing by some such process as takes place normally after the occurrence of a simple abscess of the soft parts. The *x*-ray and high-frequency currents are indicated in many cases of bone tuberculosis with sinus which are not in a condition requiring immediate operation or which have persisted after an operation. The same combination is of benefit in some cases of tubercular joint disease, probably most often in cases characterized by pain and stiffness without much serous effusion. The application would be similar to that described for tuberculosis of the spine, but the *x*-ray should be applied a little longer or a little stronger with a view to producing a slight cutaneous reaction. Especial care should be taken in applying the *x*-ray, however, not to produce an ulcerative dermatitis.

High-frequency Currents in Heart Disease.—A condenser electrode from the d'Arsonval transformer may be applied over the region of the heart in organic heart disease without arteriosclerosis. It generally gives good results, and even reduces cardiac dilatation.

Young persons with hypertension and presclerotic patients are benefited by general d'Arsonvalization. There is a lowered blood-pressure without any change in the pulse rate. The general symptoms improve.

High-frequency Currents in Gynecologic Cases.—*Leukorrhea* and *cervical erosions* yield readily to the application of a vaginal vacuum electrode, connected with the Oudin resonator or the d'Arsonval transformer. If the latter is used the patient holds the other metal electrode in her hand. If the Oudin is used the patient is connected with only one electrode. In either case the electrode should be large enough to fill the vagina and it need not have an insulated (double walled) stem. The current should be 150 milliamperes, and should be applied for ten or fifteen minutes with intermissions to allow the electrode to cool. A certain amount of massage is often beneficial, and this may be produced by moving the electrode in various directions. The treatments

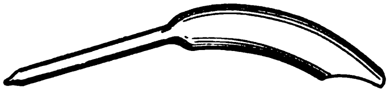

Fig. 363.—Vaginal electrode of glass for high-frequency currents.

should be given three times a week, and should be suspended during menstruation. The position for the patient is upon her back, with the legs raised and resting upon crutches, as described in the paragraph on rectal treatment (p. 591). It is much pleasanter to introduce the electrode before the current has been turned on, avoiding the sparks which would otherwise occur.

Metrorrhagia.—Cases due to small fibromyomata or fibrocystic tumors or without apparent cause have been successfully treated.[1] An ordinary copper electrode is introduced into the uterus, the vaginal portion being insulated by a rubber tube. The high-frequency apparatus may be connected with a static machine or with an *x*-ray coil, and the application should last about ten minutes and be repeated once or twice. If a static machine is used the application will probably have to be of the full available strength, but with a coil it should be regulated so that a current of about 150 milliamperes shall pass through the copper electrode. The cases required only two or three treatments, and in all three reported the effect appears to have been permanent. Other observers have noticed an uncertainty about this effect in different cases, and still others (Apostoli and the present author) have noticed a well-marked emmenagogue action from high-frequency currents. This may not be the case, however, when applied in the cavity of the uterus.

Pelvic Exudates.—These cases can very often be saved from an operation by this treatment. The vacuum electrode has an insulated stem, and the portion from which the current emerges is about 2½ inches long and ¾ inch in diameter. No speculum is required, the tip of the electrode being pushed up into the vaginal fornix as close as possible to the lesion, and then a current of 150 milliamperes is turned on. This may be a unipolar application from the Oudin, or, if from the d'Arsonval, the patient must hold the other electrode. After five minutes' vaginal treatment a similar application of 200 milliamperes is made over the lower part of the abdomen for ten or fifteen minutes. Powder is used to secure a good contact and allow the vacuum electrode to be moved rapidly over the surface without sparking. The painful area is especially treated. Relief of pain and improvement in strength are very prompt, and some weeks later the gynecologist is able to see the difference produced locally. It seems probable that this is the best electric application for these cases, and the author has cured some which had persisted after operation and all kinds of medicinal applications.

Sterility.—The author suggests the use of high-frequency currents in cases in which there is no assignable cause for sterility or in which the supposed cause has been removed by surgical measures. It stimulates not only uterine and ovarian functions but also acts as a tonic upon the whole system. The large uninsulated vaginal vacuum electrode should be used with a current of 150 milliamperes for ten minutes three times a week. He has seen this treatment followed by the prompt occurrence of conception.

Versions and *flexions* of the type which will yield to manual manipulation should find in high-frequency currents a most valuable adjunct to the other treatment by manipulation and tampons, etc.

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[1] Fanchon-Villeplée, Bulletin Officiel de la Societé française d'electricité, Feb., 1905.

The same large uninsulated vacuum electrode is to be used, and a current of 150 milliamperes is to be applied for ten minutes three times a week. The effect is to improve muscular tone and to cause the absorption of infiltrates.

General and Local Trophic Diseases.—These are amenable to d'Arsonvalization with a tension of 30,000 to 50,000 volts, 300 to 700 milliamperes, and over 500,000 alternations a second.

Myxedema.—This disease is favorably influenced by general d'Arsonvalization.

Raynaud's Disease.—Autocondensation for ten minutes at a treatment and persisted in for twelve to one hundred and twenty-five treatments, extending over periods of from one to twenty-four months, has been reported as uniformly successful in cases dependent upon contraction of the arterioles and capillaries.[1] Cases dependent upon trophic changes consequent upon arterial thrombosis or other obliteration give good results if treated by high-tension high-frequency effluves or fine sparks. The glass vacuum electrodes with an Oudin resonator make an excellent means of application.

Prognosis.—The disease is an exceedingly grave one, causing loss of one or both limbs at successive levels. These newer methods of treatment have not been used in a sufficient number of cases to make it possible to say that they will cure every case, but the results have been so good that they should be faithfully persisted in. A careful differential diagnosis should be made with a view to selecting the best mode of application.

Injuries and Diseases of Joints Treated by High-frequency Currents.—The application of the Oudin resonator current by a glass vacuum electrode is useful in the subacute and chronic stage of all these cases. A remarkable example was the cure of a case of recurrent dislocation of the patella with chronic hydrarthrosis.[2] The high-frequency application, known as thermopenetration (page 610), is especially effective in the treatment of gonorrheal arthritis and of gouty deposits about the joints.

High-frequency Currents in the Treatment of Genito-urinary Diseases.—*Chronic Orchitis or Epididymitis.*—The author has successfully treated cases of long-standing swelling due to injury The treatment has been by a combination of the *x*-ray and high-frequency currents, and care has been taken to shield the sound testis from the *x*-ray by *x*-ray metal. In the light of the recent discovery that the *x*-ray produces sterility by killing the spermatozoa a great deal of judgment is required in determining whether to use the *x*-ray as a part of the treatment. It certainly should not be applied in causes of a simple chronic inflammatory type. But in the more threatening cases, where the treatment may save the patient from an operation for the removal of the testis, the *x*-ray should certainly be combined with the high-frequency currents. The method of application is by exposure of the testis through a hole in a large sheet of *x*-ray metal, the tube being at a distance of about 10 inches, rays No. 5 Benoist. With a 12-inch coil, a Wehnelt interrupter, and the primary winding giving the greatest inductance, a primary current of 3 amperes and a current of 1 or 2 milliamperes passing through the *x*-ray tube the intensity would be

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[1] Bonnefoy, Bulletin Officiel de la Soc. franc. d'electrothérapie et de radiol., 1907.

[2] Tousey, New York Medical Journal, March 5, 1910, p. 408.

No. 6 Tousey, the exposure would be one or two minutes three times a week. The high-frequency apparatus might be the d'Arsonval transformer, in which case the patient, lying on his back, would hold a metallic electrode, while the other electrode, a glass vacuum tube in an insulated handle, is applied over that entire side of the scrotum. About 125 milliamperes would be the proper strength of current with the d'Arsonval. A spark-effect is to be avoided, the electrode should be kept in motion, the application should last about ten minutes, and should be made three times a week. The x-ray is especially effective as an alterative and high-frequency currents as an eliminative. The combination would be ideal in all these cases were it not for the drawback mentioned above, and which makes it desirable in many cases to use the high-frequency currents alone.

Tuberculosis and *cancer of any part of the genito-urinary tract* are favorably influenced by high-frequency currents as an adjunct to x-ray treatment. The amount of pus and epithelial detritus which will be gotten rid of by a single combined treatment in a case of tuberculosis of the bladder or kidney is astonishing, and the subsequent clearing of the urine and the relief of pain and the improvement in regard to frequency of micturition are most gratifying. The vacuum electrode is applied over the kidney or bladder, as the case may be, and in the latter case a rectal electrode, either vacuum or of solid metal, is efficacious. A current of 150 to 200 milliamperes is to be applied over the kidney; about 150 milliamperes over the bladder; the electrode is to be kept in motion; and the application is to last fifteen minutes three times a week. The current for rectal use is about 150 milliamperes with a vacuum electrode, and may be much stronger, up to 400 milliamperes, with a metal electrode and d'Arsonval current.

These two diseases, tuberculosis and cancer of the genito-urinary system, are further discussed in the section on x-ray treatment.

Spasmodic stricture may often be cured by high-frequency currents. Either a rectal or a urethral electrode may be used. The latter may be either a glass vacuum electrode or an electrode consisting of a metal rod covered with hard rubber. The latter type gives a shower of fine sparks even when in contact with the mucous membrane. A current of 100 milliamperes may be applied in the urethra for about five minutes three times a week. The current should be interrupted occasionally to prevent the electrode from getting too hot, and some greasy lubricant, like vaselin, is better than any of those which are soluble in water. A lubricant of the latter character will sometimes be dried up by the heat of the current and it will be difficult or painful to remove the electrode.

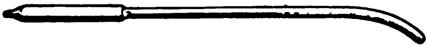

Fig. 364.—Vacuum electrode for applying high-frequency currents in the urethra.

Gonorrhea.—High-frequency currents have so decided a bactericide effect in laboratory work that it is only natural that they should have been applied in the treatment of gonorrhea. Sudnik[1] treats such a case by wrapping the penis in moist absorbent cotton, over which is a sheet of zinc to which the current is conducted, or the penis is in a

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[1] Ann. d'Electrobiologie, vol. ii, p. 313, quoted by Freund.

glass tube with a metallic bottom and containing boric acid solution. One wire is connected with the metal bottom of the tube, while the wire from the other pole of the d'Arsonval transformer leads to a metal plate, which is placed over the perineum. In women Sudnik uses a moist tampon large enough to distend the vagina and secure contact with the entire mucous membrane. This is connected with one pole of the d'Arsonval transformer, while the other metal electrode is placed over the hypogastrium. His results have been very good, the gonococci being killed almost immediately, but the discharge persisting for a week or two longer. Burdick[1] has treated obstinate cases of gonorrhea: (1) Due to streptococcus in pure culture; this yielded rapidly to treatment by a glass urethral electrode and Oudin resonator. (2) Mixed streptococcus and gonococcus infection; did not yield to high-frequency currents, but did yield to the x-ray applied so strongly as to produce a painful reaction upon the mucous membrane. (3) Gonococci mixed with tubercle bacilli; high-frequency currents failed, and rather a high vacuum x-ray tube caused a cure in seven or eight days. In the female high-frequency currents from vaçuum electrodes in the vagina sometimes caused a cure in two treatments. In a case treated by the present author the x-ray and high-frequency currents proved ineffective against gonococci. The technic consisted in the application of rays No. 5 Benoist every three days, the length and strength of the applications being such as to just fall short of producing a reaction upon the skin; and the use of a urethral electrode connected with the Oudin resonator. The treatment was begun during the first week, and was continued for several weeks without causing the disappearance of the gonococci. It was noticeable, however, that the discharge and pain were very much diminished by the first treatment, and never returned to any extent. The patient had had several previous attacks of gonorrhea.

A better method, introduced by Sudnik,[2] employs the bipolar d'Arsonval current. A metallic electrode is pressed against the perineum, and the wire from the other pole of the high-frequency apparatus is connected with a metal douche bag from which a urethral injection is given. The beneficial effects are independent of the nature of the fluid injected. A twenty-minute application is necessary, and it should be as strong as possible. Sudnik uses a 14-inch induction-coil and 4 large Leyden jars to excite his high-frequency apparatus. Sometimes in cases in which treatment is applied at the commencement of the disease there are less discharge and shreds after the first treatment, but generally the improvement is gradual.

Fulguration in Papilloma of the Bladder.—Leo Buerger and A. L. Wolbarst[3] and Edwin Beer[4] were among the first to report the application of high-frequency sparks in the treatment of papilloma of the bladder. The applicator is passed through a cystoscope, and consists of a metal point at the end of a flexible shaft made up of a spiral spring covered with rubber tubing. The Oudin resonator is adjusted to give a hot spark only $\frac{1}{8}$ inch long. The applications last about five minutes for a large papilloma and only a few seconds for a tiny growth.

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[1] New Albany Herald.

[2] Journ. de Physiotherapy, July 15, 1906.

[3] New York Medical Journal, Oct. 20, p. 854.

[4] Surgical Section New York Academy of Medicine, Jan. 6, 1911.

Dr. H. D. Furniss[1] reports the application of fulguration for freeing a calculus impacted at the vesical end of the ureter. A stream of sparks produced sufficient destruction of the overlying mucous membrane to allow the stone to escape a few days later.

The bladder should be full of water during fulguration.

Cystitis.—An instructive case is reported by Crane.[2] A lady of fifty had suffered for four months from very frequent and painful urination, especially at night. The urine was alkaline and contained 50 per cent. of pus. A slender vacuum tube was introduced into the bladder and the current from the Oudin resonator applied for fifteen minutes. She slept nearly all night and could urinate without pain. Twenty treatments, combined with the internal administration of urotropin, effected a complete cure. This agrees with the author's experience in more serious bladder cases, in which the vacuum electrode has been introduced into the rectum or applied over the lower part of the abdomen.

Fig. 365.—Doumer's rectal electrode.

Prostatitis.—Doumer[3] reports most favorable results in 122 cases of acute, subacute, and chronic prostatitis, congestion of the prostate, and prostatitis with vesiculitis. One method employs a metallic electrode (Fig. 365), passed into the rectum a distance of about 2 inches, and connected with the Oudin resonator and the strongest current and rather long treatments, eight to twelve minutes. Another method is by means of an electrode with a glass sleeve (Fig. 366); care must be taken not to use a current strong enough to puncture the glass or to produce too great a sensation of warmth. Such an electrode may be connected with a resonator, but the latter should be regulated to produce much less than its maximum discharge, effluve without sparks, and the applications should not be longer than three to six minutes. Morton wave-currents from a static machine, or similar currents from one pole of the d'Arsonval transformer while the patient holds another electrode, give results similar to those from the Oudin resonator, but are less convenient and are less agreeable to the patient.

Fig. 366.—Bissérie's electrode with glass sleeve.

Application of the Anesthetic Effect of High-frequency Currents After Urethral Electrolysis.—The irritation from the latter treatment may be relieved by the immediate use of a metallic sound connected with the Oudin resonator.

Renal and Hepatic Calculi.—General treatment by means of the autocondensation couch or of the autoconduction cage, together with local applications of the effluve or vacuum electrodes from the Oudin

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[1] Jour. Amer. Med. Assoc., May 17, 1913.

[2] Fort Wayne Medical Journal-Magazine, March, 1905.

[3] Annales d'electrobiologie et de radiologie, Jan., 1906.

resonator, have received credit for the recovery of certain patients.[1] Certain it is that the systemic condition of lithiasis is favorably influenced by this treatment. Additions to calculi already present may well be prevented and the treatment may favor the passage of some and, if possible, the absorption of others. In taking a radiograph of a case with suspected renal calculus it has occasionally happened that a stone has been passed within a day or so after exposure to the *x*-ray. During the exposure the patient receives not only *x*-rays but also an electrostatic charge, which is very similar to that derived from a high-frequency apparatus. It seems probable that high-frequency currents have some local beneficial action in the two ways indicated, but this cannot be regarded as definitely proved.

Impotence.—High-frequency currents yield good results in many cases, although, of course, there are some which seem to be incurable. An example of the benefit to be obtained in even a bad case is cited on page 592. The usual technic employs an Oudin resonator and a glass vacuum electrode applied successively to the scrotum and penis and to the dorsal and lumbar regions of the spine and in the rectum. There is no other connection made with the patient. He had better lie on his back during the application to the rectum and genitals and the current should be about 150 milliamperes. This should be applied for five minutes in the rectum and for about ten minutes over the genitals. At first no response may be evident, but after six or eight treatments vigorous erections are produced during the application. Along the spine the current may be of 200 milliamperes and with a certain amount of spark-effect and is continued for ten minutes. The electrode is kept in constant motion over the genitals and along the spine, but need not be moved during the rectal application, but the current should be turned off two or three times to keep the rectal electrode from getting too hot.

High-frequency Currents in Diseases of the Nervous System.—*Neurasthenia with High Arterial Tension.*—According to Gay, "the presence in the blood of alimentary toxins—generally acid and with a vasoconstrictor effect—and the retention of extractive substances of the xantho-uric series will cause hypertension. Not only does uric acid cause functional hypertension, which may become permanent and result in arteriosclerosis or atheroma, but chronic lead- or tobacco-poisoning, interstitial nephritis, retention of chlorids, and hyperactivity of the renal capsules, cause similar conditions. A temporary increase in blood-pressure occurs before each menstrual period and at the menopause."

Five cases, published by Gidon,[2] of Caen, France, showed a permanent reduction of arterial tension from 24 down to 16 cm. of mercury. Added to this there was relief of all the subjective symptoms which patients had suffered from hypertension. The number of treatments required varied from five to sixteen and the method was by autoconduction. The *first* patient was a man about forty, large and somewhat corpulent, and a little eczematous, who suffered especially from muscular weakness and constant pseudo-asthmatic shortness of breath. Gidon had treated him successfully with the high-tension effluve for different

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[1] Moutier, Bonnefoy, d'Arsonval, etc.

[2] Anneé Medicale de Caen, Dec., 1904, and Journal de Physiothérapie, March 15, 1905.

articular pains. The patient had taken the milk cure for hepatic trouble. The heart was normal. He formerly used to eat and drink rather excessively, now more moderately, but not according to any regular regimen. His diet was not modified at all during the high-frequency treatment. He had always digested everything very well. Gidon attributes the slowness with which the arterial tension was reduced to the unregulated regimen. After eight treatments the patient was free from all the symptoms except the eczema. During the final treatments, besides the autoconduction cage, local applications were made with an effluver with a glass sleeve; this soon relieved the eczema and the patient stopped coming. There had been three treatments a week. The *second* patient showed a rapid fall in blood-pressure with only one treatment a week. He complained of a nervous diarrhea, spinal hyperesthesia, and muscular weakness, especially in the morning. He was a pseudoneurasthenic with hypertension. The diarrhea and the debility disappeared after the first treatment, and finally the spinal hyperesthesia was cured. The *third* patient received three treatments a week. He was thin, on an insufficient dietary was constantly cyanotic, and had acute attacks of dyspnea at night. Walking was difficult on account of dyspnea, and the trouble seemed to have been brought on originally by overexertion. There had been attacks of pulmonary congestion and of acute nephritis. The heart action was rapid and suggestive of Bright's disease and very arhythmic. Treatment was by autoconduction and benefited the arhythmia very much, caused the disappearance of cyanosis, and improved the dyspnea so that the man could walk rapidly for several minutes. The night attacks disappeared. The nature of the dietary, which was partly milk, was not changed during the treatment. The *fourth* patient was a man of sixty; hemiplegic; had had two serious congestive attacks during the last two years, and his high arterial tension evidently exposed him to the danger of another. There was spastic paralysis of the arm and leg and intense mental excitability, especially at night. The cerebral condition was improved from the moment the high-frequency treatment was begun. The spasmodic contractions were relieved and walking became much easier. Constipation was relieved. There was only one treatment a week. Diet was moderate as to quantity, but unrestricted as to nature. The *fifth* patient was a young man who was very stout and who persisted in overindulgence as to diet. He was gouty, dyspneic, albuminuric, and had taken the cure at Vichy for attacks of severe hepatic trouble. He sought treatment on account of the gout, which was so bad that he could scarcely walk. Autoconduction by means of a cage connected with the d'Arsonval transformer was applied three times a week, together with the high-frequency effluve from the Oudin resonator over the painful joints, and a few sinusoidal applications. There was not much reduction in arterial tension until the thirteenth treatment, but after that time the joints were so much relieved that mechanotherapy could be applied, and from that time the blood-pressure fell steadily to about normal, the patient became able to breathe easily and to walk well, and became thinner, although still weighing over 220 pounds. His persistence in overeating was the cause of the slow reduction in arterial pressure.

Our knowledge of the value of high-frequency currents in the treatment of neurasthenia with high arterial tension is largely due to the published observations of Moutier,[1] of Moutier and Challamel,[2] and of Gay.[3] A neurasthenic with high arterial tension does not need the rest cure, and is to be regarded not as an enfeebled but as a poisoned person (Gay). No other means is nearly so effective as high-frequency currents in causing the elimination of irritant substances and the restoration of the normal blood-pressure. Under this treatment there are increased cellular activity and increased respiratory movements and chemic exchanges. The oxyhemoglobin in the blood increases and there is increased elimination of carbon dioxid. The same increased elimination is shown by changes in the urine resulting from more complete oxidization of organic substances in the system. There is an increased amount of urea. Gay gives a detailed account of the result of treatment in 12 cases of neurasthenia with high tension, and the subject is so important that his observation should be recorded here. His high-frequency apparatus consisted of a 40-inch Ruhmkorff coil with a Wehnelt interrupter, condensers, and a large d'Arsonval solenoid or autoconduction cage inside which the patient was placed. A primary current of 6 amperes and a secondary current of 350 to 400 milliamperes were used, and the application lasted twenty-five minutes every other day. Case 1: Man aged twenty-one, salesman, alcoholic ancestry, two brothers consumptive, himself a drinker and onanist. For six months he had suffered from a sensation as of a leaden helmet on his head and a general feeling of lack of strength. Melancholia and tendency toward suicide. Well nourished and well developed. No anomaly of sensation, tendon reflexes slightly exaggerated, pupils normal, no Romberg symptom (difficulty of equilibrium when the eyes are closed). In ten treatments the following changes took place: pulse rate, from 70 to 80; blood-pressure, from 160 to 120 millimeters of mercury; daily amount of urine, from 1300 to 1600 cc.; chlorids, from 6 to 10 grams per liter; phosphates, normal before and after; sulphates the same; urea, from 12 to 16 grams per liter; uric acid, from 3 to $1\frac{50}{500}$ grams per liter. The subjective symptoms all improved. Case 2: The pulse rate changed from 80 to 72 and the blood-pressure from 180 to 135 millimeters in fifteen treatments. Uric acid from 5 to 2 grams per liter and urea unchanged from 16 grams per liter. Similar changes were produced in all 12 cases, and in several which he had an opportunity to see some months after treatment the improvement had been permanent.

A series of observations by Moutier and Challamel upon a large number of patients showed a reduction in blood-pressure of 30, 40, or 50 millimeters after the first treatment by the autoconduction cage, and of only 15, 20, or 30 millimeters after the first treatment by the autocondensation couch. To verify this advantage of the cage over the couch they were able to obtain an additional reduction of 5, 15, 20, or 35 millimeters by an application with the cage after reduction by the

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[1] 1. Arch. d'electricité medicale, No. 150, Sept. 15, 1904, communication to the Medical Congress at Grenoble. "Arteriosclerosis treated by d'Arsonvalization." 2. Arch. d'electricité medicale, Feb. 15 and Sept. 15, 1903. 3. "Pseudoneurasthenia with arterial hypertension." Communication to the Societé medicale IX arr., session of April 12, 1900. 4. "Neurasthenia," communication to the Societé Medico-chirurgicale de Paris, session of Oct. 28, 1901. 5. Zeitschrift für Elektrotherapie, vol. vii, No. 2, 1905.

[2] 6. Arch. d'electricité medicale, No. 162, March 25, 1905. "Comparison between autoconduction and autocondensation in arterial hypertension."

[3] 7. Arch. d'electricité medicale, April 25, 1905.

couch. Moutier recommends five or ten minutes for each application and that they should be given three times a week. Neurasthenia with high arterial tension he calls "neurosthenia."

The presence of this symptom calls for the application of high-frequency currents of comparatively low tension. The d'Arsonval autoconduction cage and autocondensation couch are principally employed (these have been described on page 525), but other means are also used. The patient may simply hold two metal electrodes connected with the terminal of the small solenoid of a d'Arsonval apparatus, or he may hold one metal electrode while the other electrode, which may be either metallic or a vacuum tube, is rubbed over the epigastrium and along the spine. Or two metallic plate electrodes may be placed, one over the spine and the other over the epigastrium. Or, following the author's usual custom, the patient may sit upon a metal plate electrode, from which he is completely insulated by a thin sheet of indurated fiber, and may rest his back against a similarly insulated plate electrode. Each electrode is connected with the corresponding extremity of the d'Arsonval small solenoid. All the different methods produce the same oscillating currents in the body, either by direct conduction or by induction. The autoconduction cage has been more employed in Europe, but the other methods are more usual in America. Exactly which method should be selected depends upon the nature of the case, especially upon whether some local effect is desired, as well as the effect of lowering the general blood-pressure.

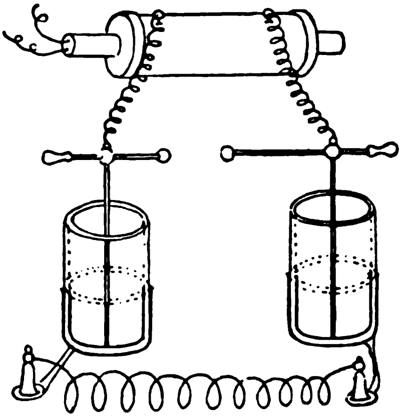

Fig. 367.—The d'Arsonval transformer with small solenoid.

The reduction in arterial tension under the application of d'Arsonvalization is accompanied by a sensation of warmth beginning in the hands and gradually extending to the body and the lower extremities. Somerville has shown that a thermometer held in the hand registers an increased surface temperature. At the same time, there is an increased amplitude in the capillary pulse and diminished tension in the radial pulse.

Paralysis.—In cases of motor paralysis the general theory of electrotherapy in the past has been to keep up the nutrition of the paralyzed muscles by causing them to contract under the influence of an electric current. The return of function in the nerve was generally expected to take place spontaneously if at all, and was thought to be only assisted by treatment. High-frequency currents produce so little muscular contraction as not to be of any service in this way. They do, however, maintain and improve the nutrition in paralyzed muscles, and seem to have an effect upon the return of function in the nerve. The author's experience has been largely with cases of infantile paralysis, and with cases of musculospiral paralysis from pressure and facial paralysis from exposure. In these cases the results have been successful. The application for paralysis is made locally by glass vacuum electrodes applied all over the affected muscles and over the spinal centers of the affected nerves. Wider observation will be required to determine the relative advantages of the high-frequency current and the galvanic and galvanofaradic currents. The vacuum electrode may be connected directly with one pole of an x-ray coil or is connected with the d'Arsonval or Oudin apparatus. A current of about 150 milliamperes should be used for about fifteen minutes three times a week. Among the cases of infantile paralysis may be mentioned one treated at St. Bartholomew's clinic. One poor little hand was crippled and about half the natural size, and the leg on that side was in the same condition. A few months' treatment with a vacuum electrode connected directly with one pole of an x-ray coil brought the paralyzed arm and leg up to a size exceeding those of the normal limbs originally, and at the age of two and a half years the boy weighed 40 pounds and was strong and jolly. There remained an indefinable evidence of the previous trouble and the author does not know whether this has completely disappeared or not. Cases of longer standing with deformities, such as talipes equinus from contraction of the muscles opposed to the paralyzed ones, of course, require mechanic and surgical treatment in addition to the application of electricity, but the latter is a valuable adjunct.

Paralysis Agitans (*Parkinson's Disease*).—Doumer and Maes[1] report a case very much benefited by autoconduction for five minutes practically every day for five weeks. The patient was an old man of seventy-two with the classic symptoms. The arterial tension became normal and all symptoms disappeared.

Epilepsy.—A combination of the x-ray and high-frequency currents has been used in the treatment of epilepsy, and the results reported by Branth[2] and Tracy[3] show that a certain amount of benefit is produced. Tracy's figures show a percentage of tentative cures amounting to 25 per cent. in petit mal, 20 per cent. in Jacksonian epilepsy, and 12 per cent. in grand mal. In these cases bromids were also administered. In a disease as inveterate as this, cures must be substantiated by prolonged freedom from recurrence, but the treatment is worth while, even if the benefit does not prove permanent. An x-ray tube with a high vacuum No. 6 Benoist, an intensity of radiation, No. 6 Tousey, and a moderate strength of current is placed with its anticathode 10 inches from the patient's head and allowed to shine for five or ten minutes (1 or 2 Holzknecht units). After this, high-frequency currents from a vacuum electrode connected either with the d'Arsonval trans-

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[1] Journ. de Physiothérapie, Nov. 15, 1905.

[2] New York Medical Journal, 1904.

[3] Ibid., March 4, 1904.

former or the Oudin resonator are applied over the brain for ten minutes and along the spine for five minutes. A current of 150 milliamperes is used. This treatment should be given three times a week, but the x-ray cannot be continued very long because of the likelihood of causing permanent alopecia.[1]

Chorea.—This is a disease in which the general tonic effect of high-frequency currents is peculiarly beneficial, and the author has treated many cases with uniform success. The application has been made by a vacuum electrode connected in some cases with vibratory currents from one pole of an x-ray coil, and in other cases with high-frequency currents from the d'Arsonval transformer or the Oudin resonator. The results have been equally good. A current of 150 milliamperes is applied for fifteen minutes along the spine and over the limbs, and while powder is used to enable the electrode to glide nicely over the surface, a certain amount of spark-effect is desirable. This should not be sufficient to be disagreeable or to bring out little red points upon the skin. The treatments should be given three times a week. Improvement is rapid and uniform. This method may be recommended in any case, but the author does not mean to say that no other form of electricity would be as good in some cases.

Locomotor Ataxia.—The author has treated cases of this disease by a combination of the x-ray and high-frequency currents. Marked improvement has resulted, so that the patient's friends have stopped him on the street and asked him what treatment he was receiving; but whether a cure can be effected in such cases remains to be seen. The improvement was especially noticeable in regard to the gait and the lightning pains. The girdle sensation persisted, but the lack of coördination was benefited, and in one case seen two years after the cessation of treatment, the patient was able to perform the delicate movements required in shaving. The technic in these cases has been the application of x-rays, No. 6 or 7 Benoist, over the spine at the lower level of the scapula twice a week, of such a duration and intensity as will produce only the slightest redness of the skin after three weeks' use, then discontinuing the use of the x-ray for three weeks and taking it up again in the same way. Vibratory currents were applied from a vacuum electrode connected directly with one pole of the x-ray coil, the current being about 150 milliamperes, and some little spark-effect being used. This current was applied to the lower extremities and along the spine for fifteen minutes three times a week (on the same days as the x-ray, and one extra day each week). The only improvements

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[1] In the treatment of epilepsy it is of the utmost importance to search for and remove any exciting causes. A case in point is that of a man of twenty-six, sent to me from the country with a history of having been wounded in the Spanish War, and having had frequent epileptiform convulsions or chorea major since then. These came on about every three weeks and usually followed some slight injury. Once he had fallen off a bicycle. Another time he caught his finger in a cog-wheel on the bicycle. During the convulsions he made frightful noises and foamed at the mouth, and it took from four to six good men to hold him, while it took the doctor two hours to get him under the influence of morphin and chloroform. After this he might wake up and recognize his friends, but more often he did not wake up until the next day. He had been treated unsuccessfully by mixed bromids and was sent to the author for treatment. Examination showed a very tight prepuce, under which was an abundant white watery discharge, the glans being fairly honeycombed by superficial ulcerations. A circumcision effected an instant and permanent cure.

that the author would suggest in this technic would be the use of the Oudin resonator and the application of a high-frequency current of 200 milliamperes without much spark-effect, keeping the glass electrode in motion; and the application of a quantity of the *x*-ray actually measured, as by Holzknecht's chromoradiometer, and amounting to a little less than 1H. twice a week. The anticathode of the tube is about 11 inches from the skin, no localizer being used. In inexperienced hands the *x*-ray should not be applied over the spine. It is not at all probable that pathologic changes can be produced in the spinal cord by rays which do not injure the skin, but at the same time it would be unwise for one who was not sure of the strength of ray produced by his apparatus to take the risk.

Neuritis and Neuralgia.—The author has treated a great many cases coming under these headings. Usually the results are excellent and the improvement prompt. Occasionally a case will be found to experience somewhat more pain after the first one or two applications and then to do perfectly well. In other cases, after a reasonable trial, the high-frequency currents may be abandoned and, as in certain cases of long-standing facial neuralgia, static electricity will effect an immediate cure. The *x*-ray has done great service in cases of pain about the face by enabling one to examine the condition of the teeth, the bones of the face, and their various pneumatic sinuses. Guided by this means, no time is wasted in treating by electricity a case in which an operation is the only proper thing. Such cases may be suppuration of the antrum or of the frontal sinus, impacted teeth, abscess about the apex of the root of a tooth, an improper root-filling (insufficient or penetrating the tooth either at the side or the apex of the root), or a tumor, abscess, or cyst of any of the bones. The *x*-ray does not show the condition of the nerve directly, but enables us to exclude certain other lesions and narrow the diagnosis down to that of a painful affection of the nerve itself. This may have more or less of an anatomic basis, according to whether the case is one of neuritis or neuralgia. The method of application may have to be varied for different cases, the local application by the effluve or from a vacuum electrode being usually much more effective than the general application by autoconduction or autocondensation. In this regard the high-frequency current differs from static electricity, a general application of which is often more effective than a local one in these cases. In many cases of sciatica, lumbago, neuralgic pains in the face, neck, or limbs the author has obtained excellent results from the direct application of the vacuum electrode to the point of exit of the nerve and all over the painful area. These results have ensued whether there was just a single glass vacuum electrode connected directly with one pole of *x*-ray coil, or with the Oudin resonator (Fig. 368), or whether the d'Arsonval transformer was used. With the last-named apparatus the patient holds a metallic electrode in one hand while the glass electrode from the other pole of the apparatus is applied to the affected region. In any case the skin should be powdered and a current of 200 milliamperes applied during fifteen minutes for sciatica, or 150 milliamperes during six minutes for trigeminal neuralgia. This should be given every other day. Two or three weeks usually sees the milder cases cured, while those of long standing may take two or three months. The strength of current prescribed is that which actually passes through the glass vacuum electrode. There should be but a slight spark-effect. The pain-relieving property of high-frequency currents and their tendency to relax spasm, together with the fact that they do not cause muscular contraction or any disagreeable sensation, make them the method of choice in these cases. An extreme case is reported by Somerville,[1] in which ataxia, muscular weakness, and anesthesia improved very much under treatment by high-frequency currents. The trouble began with numbness and weakness in one leg, causing the patient, twenty-one years old, to resign his position as a postman. In consequence of exposure in a rainstorm the condition became much worse and he was confined to bed with motor and sensory paralysis of both upper extremities, as well as both legs. The symptoms did not indicate locomotor ataxia, but rather peripheral neuritis. There was no history of syphilis or of alcohol. On recovering from this acute attack he was left with a staggering gait and weakness in the limbs, and sensation in the hands was impaired. It is sometimes thought that high-frequency currents succeed in neuralgic patients with depression and are not so good for those who are nervous and excitable. The statement is made that in some of the latter patients the pain is aggravated by this treatment. The author does not find this to be the case

Fig. 368.—Method of applying high-frequency currents in trifacial neuralgia.

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[1] Archives of the Röntgen Ray, London, March, 1905.

when the application is made locally by the vacuum electrode. The effect of the autoconduction cage or the autocondensation couch is systemic and, of course, will be suitable in some cases, while it is contraindicated in others. The local benefit would not be obtained if the application affected the general nervous system unfavorably. The local application hardly ever fails to have a favorable influence on the general condition, and while not always successful, there is no class of cases in which it is especially likely to fail.

The high-frequency application, known as thermopenetration (page 610) has often given good results in the author's practice. It is especially suitable for cases with one or more definite painful areas; while the other cases with general pain and weakness in an entire limb are treated by the slow sinusoidal current and four-cell bath.

Neuralgia.—Bipolar effluviation from double resonators or double spirals may be followed by sparks from a monopolar Oudin resonator. A method which has succeeded well in the author's hands has been by a glass vacuum electrode connected with a monopolar Oudin resonator. The voltage and amperage have to be carefully studied for each case.

Neuralgia of the Lumbar Plexus.—Heavy galvanic currents may be used.

High-frequency currents may be applied from the d'Arsonval transformer. The patient holds a metallic electrode while the wire from the other terminal leads to a plate electrode covered with wet cotton which is applied to the lumbar region. Or the glass vacuum electrode may be substituted for the moistened plate electrode.

Chronic Sciatic Neuralgia.—This is by far the best application for these cases. Suitable methods of application are:

1. Autocondensation for about five minutes, the patient sitting upon the insulating indurated fiber covering a sheet of metal while his back rests against another. This the author follows by a mild or strong application of a glass vacuum electrode from the Guilleminot spiral along the course of the sciatic nerve and its branches. Whether to redden the skin or not is a question to be decided in each individual case, but generally mild applications are the more beneficial. Five minutes is about the proper duration. Vibratory massage along the course of the nerve in the thigh is a desirable addition in some cases.

2. A method recommended by Albert Weill employs first a bipolar effluve and then monopolar sparks. A large plate electrode from the pole of one of the resonators or spirals is directly in contact with the lumbar region, and a brush electrode or effluve is held near successive parts of the painful region until the latter is all reddened. This anesthetizes the skin to a certain extent and prevents pain from the second part of the treatment. A series of large white monopolar sparks are applied along the nerve. These turn the skin white, but it soon becomes vividly congested and the sciatic pain is immediately relieved and the patient able to walk better than he could. Some of the improvement persists until the next treatment. Applications are made at first every day, then three times a week, and a complete cure is to be expected.

Sciatic Neuritis.—The d'Arsonval apparatus is used, giving a bipolar high-frequency but comparatively low-tension discharge. One wire passes to a sheet of lead or tin applied directly to the lumbar region and the other to a similar electrode fastened to the leg below the calf.

The milliamperemeter should indicate a current of 300 or 400 or more ma. and the application should last about ten minutes. Bordier recommends this method very strongly.

The mildest application of a glass vacuum electrode connected with a monopolar Guilleminot spiral and with an adjustment of apparatus giving a discharge of 150 ma. with scarcely any spark-effect has given wonderful results in the hands of the author. One case of two years' standing was cured in seven applications and remains well now, three years later.

Insomnia.—When this condition occurs as a symptom of any disease in which high-frequency currents are indicated, it is usually cured by such treatment. This happened in a case of gastric atony treated by the author. The application was by a vacuum electrode connected with the Oudin resonator, the electrode being passed over the abdomen and along the upper part of the dorsal region of the spine. But where insomnia is the chief symptom and almost constitutes a disease it is not always best to treat it by high-frequency currents. In any case the method of application must be carefully studied. Somerville,[1] using Gaiffe's transformer and high-frequency apparatus with 800 to 1000 milliamperes passing through the autocondensation couch, has succeeded with such cases after fifteen to thirty treatments. Drowsiness is not always one of the results of high-frequency currents and improvement in regard to sleeplessness comes as the result of a number of treatments. The application does not, like hypnotic drugs, induce an unnatural sleep, but rests and invigorates the patient, and so brings about natural sleep. Too long or too strong an application of high-frequency currents is liable to cause sleeplessness by its effect upon the circulation in the brain. The application of a glass vacuum electrode, with a current of 150 milliamperes, to the back of the neck and head for about five minutes will almost always have a reflex soothing effect. This will tend to produce sleep through an effect on the nervous system.

Painful Conditions Not of Nerve Origin.—*Pleuritic pains* are well treated by the glass electrode with 200 milliamperes from the Oudin resonator for ten minutes every other day.

Painful flat-foot is one of the conditions in which the application by the vacuum electrode is of the greatest benefit. A current of 150 milliamperes is applied for fifteen minutes to the foot and leg three times a week. The apparatus may be either the d'Arsonval transformer or the Oudin resonator or the vacuum electrode may be connected directly with one pole of an *x*-ray coil. Powder should be used and only the slightest spark-effect allowed. There may be some advantage in using the d'Arsonval transformer and having the patient hold the other metallic electrode. In the author's cases this has seemed to produce a little more tonic effect than the unipolar application. Flat-foot plates are, of course, a necessity in these cases. When the disease is simply weakness, as shown by pain and the characteristic footprint, the combined electric treatment and mechanic support relieve these cases very promptly, and eventually effect a complete cure, but when the disease is of long duration and there is deformity of the bones a surgical operation may be necessary before electricity is indicated.

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[1] Illinois Medical Journal, June, 1905.

High-frequency Currents in the Treatment of Cicatricial and Fibrous Conditions.—*Dupuytren's Contraction.*—This is a condition which occurs in middle or advanced life and is due to a contraction of the palmar fascia, with adhesions to one or more of the flexor tendons and to the skin. It is evident on looking at the hand, and especially so when an attempt is made to fully flex or extend the fingers. Herdman[1] has treated these cases successfully by high-frequency currents and calls attention to the fact that the trouble is not a contraction of the tendon, for it is the proximal phalanx of the finger that is flexed, and no position of the hand will permit it to be extended. Then, again, contraction of the tendon would not cause the prominence of the tendon which is seen in these cases. A rheumatic or gouty tendency is usually found in such cases and sometimes neuritis of the ulnar nerve. The local condition is a chronic inflammatory process due to the systemic state, and bearing no distinct relation to the use which may be made of the hand in the patient's daily life. The rôle of high-frequency currents in the treatment is to cure the constitutional tendency. A suitable application is made by means of the autoconduction cage or the autocondensation couch. The author has more frequently used the vacuum electrode, applying a current of 150 to 200 over about a quarter of the surface of the body during fifteen minutes. The surface is powdered and the electrode kept in motion. The use of the tissue oscillator over the hips and lower part of the back for a couple of minutes is a most desirable addition. The galvanic current with negative electrolysis, using only a few milliamperes, has cured the local condition.

High-frequency Currents in the Treatment of Certain Constitutioual Diseases.—*Diabetes.*—Static electricity and high-frequency currents are both of value in diabetes, but should probably be limited to cases in which metabolism is slowed. They may do harm in cases where there is exaggerated denutrition and the examination of the urine shows a nitrogenous coefficient higher than the normal. DeRenzi and others have seen the return of sugar caused by high-frequency applications in such cases.

Conflicting reports have appeared in regard to the efficacy of the treatment in this disease. D'Arsonval reported 2 successful cases as long ago as 1896. Both feet rested in a bath to which one electrode went; and the other electrode, a forked one, was held by both hands. Apostoli, at the Twelfth International Medical Congress, reported success in over 500 cases. Autoconduction cages or autocondensation couches were used and the average number of treatments was twenty-five. Following Apostoli, several of his pupils and assistants have reported successful results. Some others who have succeeded with it are Williams,[2] Allen,[3] and the present author. On the other hand, Boedeker, Cohn, Loewy, Doumer,[4] and more recently Halfon,[5] have reported that high-frequency currents produced no reduction in the amount of urine. Freund ("Radiotherapy") does not express an opinion.

The author knows that in certain cases the sugar will not disappear, but believes that even in these cases the general strength

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[1] Archives of Physiologic Therapy, February, 1905.

[2] High-frequency Currents in the Treatment of Some Diseases.

[3] Radiotherapy, etc.

[4] Annal. d'electrobiologie, vol. iii.

[5] Il progresso medico, No. 3, 1903.

and the cutaneous and other disagreeable symptoms are so much benefited as to make high-frequency currents a necessary part of the treatment of every case. That there are many other cases in which the sugar disappears in a most wonderful manner is equally certain. It has not been the author's habit to ask for a discontinuance of medicinal treatment, and so his own cases can hardly be cited as absolute proof that the electric treatment alone would have been effective. But what he is able to say is that cases which have been doing very badly under medicinal treatment alone have done very well under the combined medicinal and electric treatment. One such case was that of a lady about forty years old who was passing about 56 ounces of urine daily, and this contained 10 per cent. of sugar. She had distressing abdominal symptoms consisting mostly of pain and diarrhea.

Three weeks' combined treatment by medicines and the *x*-ray and high-frequency currents reduced the amount of urine to 55 ounces a day and the sugar to less than 1 per cent., and the patient left for her home in Porto Rico feeling entirely well. Another similar case was that of a gentleman of fifty-five who had suffered from asthma and dyspnea for a month or two, and progressive and terrible emaciation and loss of strength. He had lost 25 pounds in six weeks and the urine (61 ounces a day) contained 10 per cent. of sugar, or 2751 grains per diem. He was so weak that his wife had to dress him, and he was apparently hurrying toward a fatal termination. In his case also the *x*-ray was used in conjunction with high-frequency currents, and the administration of arsenical preparations was continued. During the next two and a half weeks there was practically no loss of weight —only 4 pounds—and by the end of that time a change for the better set in. He began to gain weight and strength, and it was evident that his life was saved. After one or two weeks more of treatment by high-frequency currents without the *x*-ray he was again placed in the hands of his regular physician for treatment by static electricity, and made a good recovery.

As indicated above, the French operators have generally made use of the methods of general electrification which employ the autoconduction cage or the autocondensation couch, and if either of these are used a current of at least 500 milliamperes should be applied; and the séance should last fifteen or twenty minutes and be repeated every other day. The author's own preference is for the *x*-ray, rays No. 5 Benoist, applied over the abdomen twice a week with the anticathode 13 inches from the skin and the applications long and strong enough to produce some tanning of the skin in three weeks, but no redness. About half the normal exposure described on p. 1048 is suitable for these cases. The vibratory currents in both of the foregoing cases were applied by a vacuum electrode connected with one pole of an *x*-ray coil, and a current of about 200 milliamperes was applied over the abdomen and up and down the spine for about twenty minutes three times a week. The skin must be powdered to allow the electrode to glide smoothly over the surface without sparking. The Oudin resonator is rather more convenient when as heavy a current as this is desired and will probably give equally good results. Even in cases where the amount of urine and the percentage of sugar are not reduced the dryness in the throat and the pruritus are relieved and the patient feels better. It is uncertain whether in the cases which do most favorably the disease is actually cured or whether the patient is only made practically well. Some preparation of arsenic seems to be the medicinal agent for use in conjunction with the electric treatment.

Rheumatism.—Jones[1] considers this treatment contraindicated in acute rheumatism and says that it gives good results in chronic rheumatism, but requires a large number of treatments, twenty-five to thirty at least, and sometimes two or three hundred (Apostoli and Laquerriere). There is no difference of opinion in regard to its being of value in chronic rheumatism, but some operators think that it has not yet been shown to possess any advantages over other forms of electricity, such as electric baths and static electricity. The convenience of application and the ease and certainty with which the application can be regulated make this the ideal method of treatment if it be shown to be effective. Here, as in other constitutional disorders, many operators employ autocondensation or autoconduction, but the author finds the application of the glass vacuum electrode to the affected joints or other localities and then over the abdomen and along the spine or in some other way to apply it to a large part of the body very effective. The cases which have been treated in this way have been referred by their family physicians after medicines, massage, and baths had failed to give relief. The results are permanent, not mere temporary stimulation or analgesia, and a healthy action of the tissue cells throughout the body is inaugurated which results in continued improvement after the treatment is all over. In many cases there will be wonderful improvement within a few hours after the first treatment, and this improved level is maintained but not materially surpassed for about three weeks. At the end of this time a gradual and uniform improvement begins which continues as long as the treatment is kept up and for some time afterward, so that often the patient feels better a year after the treatment was stopped than he did immediately afterward. Some of the cases which have been successfully treated have had pain and enlargement and stiffness of several of the large joints and of some of the smaller ones, but without serous effusion. The symptoms have entirely disappeared except that perhaps some one finger joint may remain a little enlarged, though painless. Cases with rheumatic synovitis of almost every joint in the body and of many years' duration may be very much benefited, although in some of these a cure is not to be hoped for. The benefit is shown by the prevention of the acute exacerbations which every change of weather and certain other conditions bring on. There is also a return of the joints to about the normal appearance and the deposits about the sheaths of nerves and in the region of the joints is removed or diminished. The patient becomes able to sleep and his general condition improves very much. From being sick in bed from a tenth to a quarter of the time, such a patient may often be transformed into a condition of apparent robust health. An expert examination may show, however, that the synovial membrane of nearly every joint is still thickened, and an occupation involving prolonged exposure to cold and wet would be liable to bring on an acute exacerbation.

There are many cases which other means have failed to cure and which high-frequency currents will cure either completely or practi-

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[1] Medical Electricity.

cally. Other cases must be classed as incurable, though they may be very much relieved by this treatment.

The author's method of treatment has been published[1] and consists in the application of vacuum electrodes from the d'Arsonval transformer or Oudin resonator to the affected joints and to a considerable portion of the body; for instance, over the abdomen and along the spine. The current is about 200 milliamperes and the application requires from one-quarter to one-half hour. With this is applied mechanic vibration along the spine and perhaps over the abdomen. In occasional cases the *x*-ray is applied to remove some obstinate and painful swelling about one particular joint. The high-frequency current has a strength of about 200 milliamperes; and severe cases with several large joints to be treated require an application of about one-half hour. A certain amount of spark-effect is desirable over the joints, but this should be only the fine crackling that comes when a convex electrode is in good contact with only a portion of its surface touching the skin. The skin should be powdered and the electrode kept in motion. Treatment three times a week is best, but twice or even once a week will often accomplish a cure, though a longer time may be required. The result is due partly to a local stimulant and counterirritant effect and partly to a constitutional effect. By the latter the defective processes of metabolism are corrected. Nitrogenous substances, for example, leave the body completely oxidized as urea, instead of partly oxidized as uric acid. Whether or not it is correct to regard uric acid as the cause of rheumatism, it seems to be a fact that it is present in the tissues and excreta to an abnormal extent in these cases, and that measures which result in its diminution have a curative effect upon the disease. Williams[2] observed in one case that the proportion of uric acid to urea in the urine was at first 1 to 51 and gradually changed to 1 to 70, then gradually changed all the way back to the normal ratio of 1 to 35. The change accompanied the recovery of the patient from a case of chronic rheumatism. The symptoms had been "rheumatic fever at twenty-six years; now at forty-eight there are dyspepsia, rheumatic pains all over, but especially in the lumbar region, and history of several big-toe-joint attacks. Small joints all more or less enlarged. Appetite nil and sleep bad." He was treated by autocondensation ten minutes daily with a current of 350 milliamperes; and in seven weeks made a complete recovery and gained 6¼ pounds in weight.

In the majority of cases treated there is no special change in the daily excretion of urea, and very often the examination of the urine does not show any reason why there should be chronic rheumatism. The cases cited in the author's article in the "Medical Record" are instructive.

One patient was a man aged fifty-four, with a family history in which occurred rheumatism (fatal in his father's case at thirty-nine), "ossification of the heart," paralysis of the throat, and apoplexy, on the paternal side; all of his male paternal ancestors being large men. His maternal ancestors were all delicate and died at an early age without special diatheses. He himself had had no illness since childhood except an attack of acute articular rheumatism which kept him in bed for a month. The maximum temperature was 103.8° F. His

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[1] Medical Record, March 5, 1905.

[2] High-frequency Currents in Certain Diseases.

present trouble dated from an attack of lumbago two years ago. He was not sick in bed, but any movement was very painful in the morning, with gradual improvement through the day. The symptoms disappeared in two months. Status præsens: 6 feet 4 inches in height, weight 175 pounds; some flat-foot and consequent unusual breadth to the ball of the foot. The right great toe joint is swollen and stiff and there is a gouty pain in it, especially on awakening. The middle toe of the right foot has a sensation as of slipping out of joint. There is a rheumatic pain in the right hand. These symptoms have remained so aggravated, in spite of medicinal treatment, as to threaten to incapacitate him for business. Shortly after beginning treatment he had a fall which produced a severe ecchymosis of the left thigh and stiffness of the knees and an added rheumatic pain in the left hand. The treatment consisted in the application of high-frequency currents and vibratory massage according to the author's *uric-acid technic* and the administration of 10 grains of salophen three times a day; the avoidance of tea, coffee, and tobacco, and the application of flat-foot plates. At the end of a month the gouty pain in the right great toe had almost disappeared; only a trace remained of the rheumatic pain in the right hand, and the rheumatic pain in the left hand brought on by the fall had been reduced three-fourths. After another two weeks' treatment the patient reported himself so well in every way that it seemed proper to discontinue the treatment.

The very marked effect of the first treatment was produced before he had begun taking salophen, but the latter is a valuable adjunct in these cases. The patient came a year later to report his condition, which was excellent. This patient and the next one were in private practice and were cultivated people, but accustomed to simple rather than luxurious living.

Another patient was a lady of fifty-four, weighing 287 pounds, and with a family history of rheumatic gout, making them chair invalids for years. Personally she had always been careful about diet, but had gradually become more and more affected by a rheumatic or gouty condition which, in spite of medical treatment, had finally crippled her. For some time previously she had not been able to walk more than two or three blocks and on coming to a curbstone would hesitate for some time before attempting to step up those 2 or 3 inches. The knees were badly swollen, the joints of both feet were stiff and swollen, as was also the middle finger of the right hand. The day following the first treatment she was walking any number of blocks, going up and down stairs, and "feeling like a bird." This was before she had begun taking salophen. The original brilliant improvement remained, but was not surpassed until after two or three weeks of treatment applied two or three times a week. Then a steady advance began. The localities exhibiting the slowest progress were one knee, which she had strained some time previously, and the middle finger of the right hand. To these several applications of the x-ray were made. For this an 8-inch coil was used with a Caldwell-Simon interrupter and a Müller heavy target tube which was encased in a localizing shield. The holes in the interrupter were small and gave a primary current of 4 amperes with rapid interruptions, rays No. 4 Benoist. The anticathode was at a distance of 9 inches from the skin with exposures for two minutes twice a week. The beneficial effect was immediately evidenced by prompt improvement in the knee and finger.

A *vibrator* used in these cases was made by Wappler, of New York, it has a $\frac{1}{16}$-horse-power motor, a flexible shaft, and a ball extremity in which an excentric weight revolves. The ball is applied laterally so as to produce the effect of pressure and release with short rapid strokes, but without loss of contact. The speed and the length of the stroke is regulated for each case. The effect is to stimulate any nerve, if it is applied lightly and for a short time; and to depress or produce a sedative effect on any nerve over which it is applied with heavy pressure and for a long time. The effect of vibration in rheumatism is partly one of stimulation of the general metabolism, and partly also an effect upon the trophic centers in the spine, which influence all the tissues of the different joints they supply. Even without electric or other special devices the author has for many years prescribed massage of the posterior roots of the spinal nerves for cases of rheumatism of the knee, for example, which did not yield to medicines and local applications. This was very successful and made it easy for him to believe some of the claims of osteopathy when that theory was promulgated.

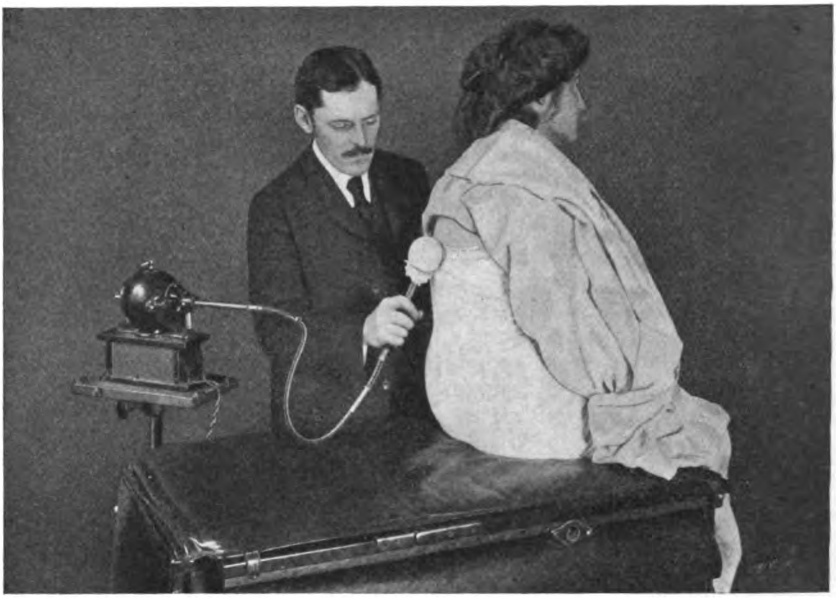

Fig. 369.—Electric vibrator for mechanic massage.

The patient was under treatment by high-frequency currents and mechanic vibration for four months, and at the end of that time seemed entirely well, though there remained a little enlargement of the joint of the middle finger. Many months afterward she reported continued increase in health and strength, and thinks that the greatest benefit came after the treatment was finished. At the present time, four years later, she is more enthusiastic than ever about it. The treatment produces a permanent change in the system, not a mere temporary stimulation.

Obesity.—Arthritic and gouty patients suffering from obesity are benefited by autoconduction or autocondensation or by the general application of a glass vacuum electrode while the patient holds a metallic electrode connected with the other pole of the d'Arsonval transformer.

There is sufficient evidence that autocondensation or autoconduction will reduce the size of fat people by stimulating the processes of metabolism. It is uncertain, however, whether a reduction in weight may be regularly expected, or only a certain reduction in bulk. Quite extensive applications with the vacuum electrode proved only moderately successful in the case of a patient who weighed 210 pounds, though only 5 feet 4 inches in height, and who had the marked somnolence which would naturally be expected. He would go to sleep while reading the newspaper, or on the street car on his way to be treated, or in the reception room, and invariably upon the operating table. He lost 6 pounds in six weeks' treatment and improved materially in regard to the drowsiness. It seems probable that the treatment by high-frequency currents is not the first choice in cases of obesity unless they present some special indication for it in addition to mere weight.


Fig. 370.—Hanfeld tissue oscillator.

A more effective method of treatment is by mechanic means, and the best apparatus is a *tissue oscillator.* This has a powerful electric motor, the speed of which is regulated by a rheostat. A heavy iron pillar supports a revolving shaft and the pulleys on the motor and shaft may be so adjusted as to give from 300 to 2400 revolutions a minute. Close to each end of the shaft is fastened a pin which may be adjusted more or less excentrically. Two handlebars are thus given a back-and-forth motion, the length of stroke being set at from zero to an inch or more. For certain purposes the handles may be held in the two hands and pulled while the machine is put in very moderate motion. An acute attack of stiff neck, or of myalgia about the shoulder, is relieved by three or four minutes of this application. For most purposes a belt is attached to the two handlebars and passed around the patient, who steadies himself by the handles and leans all his weight against the belt. For obesity the belt is applied over the buttocks for five minutes, the patient facing the machine; then over the abdomen and over the shoulders. The stroke should be about ½ inch and must be exactly even on both sides. The adjustment is such that one side pulls as the other relaxes. If the proper adjustment be made and a suitable speed given, usually about 1200 revolutions a minute, the patient rests quite steadily against the belt and is not jolted back and forth at all. At the same time the flesh under the belt is moved to and fro laterally and there is a general tremor given to the whole body. The local effect is to bring the blood to the surface and to create intense itching, which lasts for two or three minutes after the cessation of the treatment. Masses of fat fairly melt away under this treatment and, as indicated above, the application can be made where it is most required. In some cases the author has effected a reduction of 1½ pounds a treatment, three times a week, without any other exercise and with only ordinary care about diet. Patients who are simply large but not fat are not apt to yield much in weight to this treatment, and perhaps could not be expected to do so without a bad effect upon their general health. But even these may sometimes be improved by it. A man's abdomen or a woman's shoulders, bust, or hips may be reduced by this means just as by the more natural means of outdoor exercise.

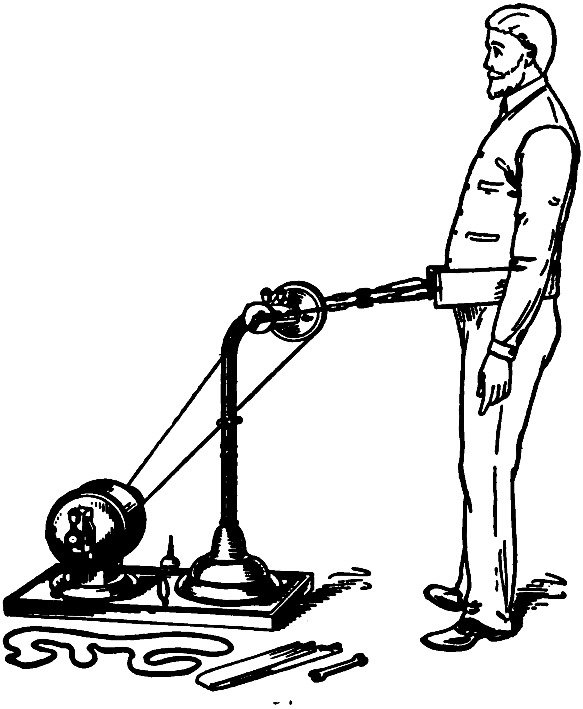

Fig. 371.—Hanfeld tissue oscillator used for reducing weight.

The Tissue Oscillator in Uric-acid Cases.—In gout, rheumatism, or neuritis, or any of the many conditions likely to occur in men and women who eat and drink an abundance of rich food and wines, and who, while perhaps doing plenty of mental work, get very little physical exercise, this treatment is of the greatest value. It gives the necessary stimulus to digestion and circulation, and is a valuable adjunct to electric treatment.

Gout.—High-frequency currents applied by autoconduction or autocondensation—or, in the author's practice, especially by vacuum electrodes—give excellent results in this disease. Most writers do not recommend this treatment for acute attacks, and some even say that it may precipitate an acute attack. The author's experience leads him to believe, however, that the treatment affords relief at any stage of the disease and that any case may be treated with a view to producing a cure after a complete course of treatment. If the autoconduction cage or the autocondensation couch is used, the current should be 500 milliamperes or more, and the application should last fifteen minutes and be given three times a week. If the vacuum electrodes are used they should be exhausted to the degree which will give the richest lilac-colored glow and the greatest amount of ultraviolet radiation, as detected by the fluorescence caused in a piece of Willemite. The current should be about 200 milliamperes from either the d'Arsonval transformer or the Oudin resonator and should be applied over the whole of the affected limb for fifteen minutes, keeping the electrode in motion and avoiding spark-effect. The current should be reduced to 150 milliamperes over any eczematous areas and over acutely inflamed joints. The treatment should be applied three times a week. The patient ought to feel entirely well in six weeks, but to consider the treatment finished, two or three courses of treatment lasting six weeks each should be given separated by intervals of about two weeks. The tissue oscillator is applied with the belt around the hips and the patient facing the machine. A mild application is made for two or three minutes. In this disease, as in rheumatism, the effect of the first treatment is often wonderful. The author has had patients who expressed doubt as to its being due to the treatment at all. They said it must have been a coincidence, but the subsequent course of events convinced them that it was the result of the electric applications. After the first treatment the improvement is no longer by jumps, but is gradual and uniform, and is much more rapid than in rheumatism. The same vacuum electrodes completely heal the chronic or subacute eczema which is present in so many of these cases. This is accomplished in the first few weeks.

Gouty deposits about different joints are often removable by the high-frequency application called thermopenetration (page 610).

Arteriosclerosis.—The application of high-frequency currents, especially by the autoconduction cage, has a marked effect in reducing functional arterial hypertension. This effect will be described in greater detail in the paragraph upon neurasthenia with high arterial tension, and its successful employment in that disease has led to the use of this treatment in arteriosclerosis. In the early stages of this disease the high arterial tension is due to vasomotor spasm caused by the same auto-intoxication which, acting through many years, is likely to cause structural changes in the walls of vessels and in every organ of the body. The auto-intoxication alluded to is often the effect of a sedentary life, with or without the influence of alcohol, and is especially the result of mental strain in business or professional life. It develops during middle or late life, and is a condition in which irritant substances, analogous to those in uremia, circulate in the blood and produce the functional and, finally, the increasing structural changes referred to.

Many of the ailments of later life—rheumatic, hepatic, gastric, and nervous—are the natural results of arteriosclerosis. In the early stages this disease can probably be cured, and one of the best methods of treatment is by high-frequency currents. They not only promptly reduce the blood-pressure but also cure the condition of defective metabolism and elimination which is the cause of the trouble. During the treatment the patient may be completely clothed as he sits inside the large solenoid, called the autoconduction cage, or lies upon the insulated cushion of the autocondensation couch. Either apparatus is connected with a d'Arsonval high-frequency apparatus actuated by an x-ray coil, a transformer, or by a powerful static machine. A current of 500 milliamperes or more passes through the cage or the couch, the patient not being in direct connection with the apparatus at all, but receiving an electric induction. The electric effect upon the patient is analogous to the induction of a powerful current in a secondary coil by the passage of a current through a primary coil with which it is nowhere in contact and from which, in fact, it is most carefully insulated. The applications last fifteen minutes and should be given every other day for about three weeks. In an early stage of arteriosclerosis each treatment may be followed by a fall in arterial pressure amounting to 20 or more millimeters of mercury. Before the next treatment the pressure rises again, but not to its original level, and gradually the normal level is reached and maintained. In advanced cases of arteriosclerosis this treatment is also to be recommended, and the author's experience with it has included cases in which some one effect —such as rheumatism, neurasthenia, embolus, or hemianopsia—has required treatment. Electric-light baths also give excellent results in arteriosclerosis.

High-frequency Currents in Diseases of the Lungs.—*Bronchitis* and *asthma* may be relieved by the application of high-frequency currents to the chest-wall, preferably using a vacuum electrode with a current of 150 milliamperes, although the French writers use the effluve with some direct sparks. In either way a revulsive and tonic effect is obtained which would certainly be of benefit in these cases.

Tuberculosis is certainly susceptible of wonderful benefit by high-frequency currents, but as with every other form of treatment, some cases get only moderately well and eventually die of the disease. Other cases apparently get entirely well and may or may not have a return of the trouble at some future time. And in these cases who can say just what rôle the treatment has played in the process of recovery? The author's own technic in these cases includes the use of the x-ray and the mercury vapor electric light besides the high-frequency currents. But it is interesting to note that dozens of apparently complete cures have been reported by means of high-frequency currents alone (Doumer, Gandil, Oudin, Williams, Bowie, etc.). The method employed has usually been by the effluve from an Oudin resonator applied over the chest for five or ten minutes daily, especially to the supraclavicular regions. The strongest possible discharge was used and a certain number of direct sparks were allowed to pass to the surface of the body. The sequence of events has been improvement in the general health, disappearance or reduction in the number of bacilli, diminution in cough and expectoration, and, finally, improvement in physical signs.

An instructive case in the author's practice was that of a young woman with tuberculosis of the lungs and larynx. The throat specialist could see an ulceration below the true vocal cords. She had no voice at all and was unable to swallow anything but liquids. The expectoration was so profuse as to choke her and it was full of tubercle bacilli. Treatment was begun in December, 1903, and consisted in the application of the x-ray, the mercury vapor light, and high-frequency currents. The x-ray was used once in five days, the anticathode of the tube being 15 inches from the nearest surface of the chest and the time of exposure four minutes in front and four minutes behind the chest. A 40-cm. heavy anode Gundlach tube was used and an 8-inch Ruhmkorff coil with a Caldwell-Simon interrupter. The rays were about No. 4 of the Walter or Benoist scales and the current passing through the primary coil was about 4 amperes. Immediately after this application a Morton treatment tube similar to the author's special x-ray tube, described under the treatment of diseases of the mouth by high-frequency currents, was applied to the outside of the larynx. The extremity of the tube was in contact with the skin and a total exposure of two minutes was made over different aspects of the larynx. No other treatment was applied on these days. Between each two x-ray treatments a treatment by the mercury vapor light and high-frequency currents was given. The Cooper Hewitt lamp, 400-candlepower, was placed within 5 inches of the bare chest for ten minutes in front and ten minutes behind. This made the skin feel hot to the touch, but occasioned no redness or perspiration. The lamp was so arranged that the patient's eyes were shielded from the light. Immediately after this a glass vacuum elec-

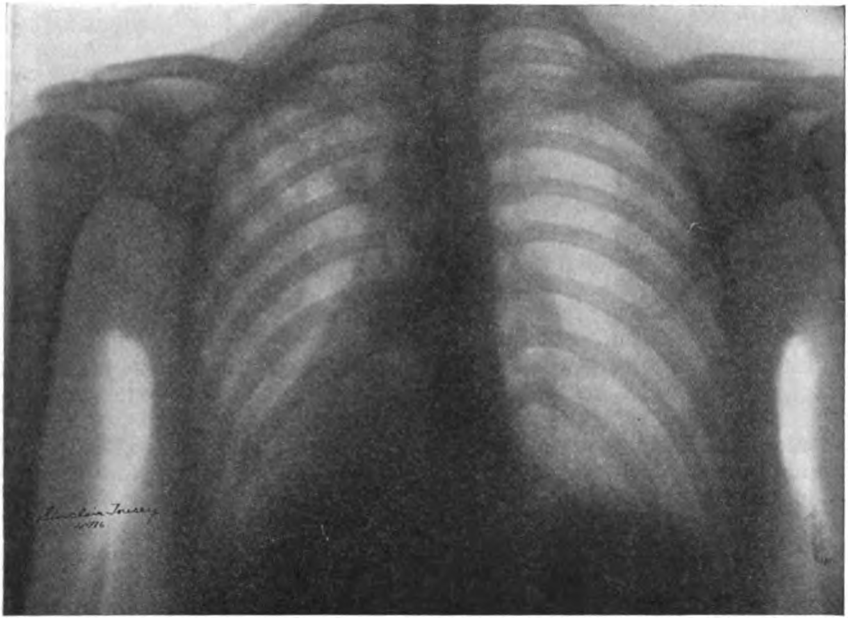

Fig. 372.—Chest of patient with tuberculosis of the lungs and larynx treated by x-ray, mercury vapor light, and high-frequency currents.

trode was applied all over the chest and neck. The electrode was connected directly with one pole of the x-ray coil, about 3 amperes of primary current were used, and care was taken to have a good contact and avoid a spark-effect. The result was extremely encouraging. In three weeks her voice became good enough to talk over the telephone and the expectoration ceased. In three months the throat specialist reported that nothing remained of the ulcer, but in its place there was a white line of cicatrix. She was able to eat everything and had gained 4 or 5 pounds in weight. This was the condition of things when the progress made in the case was reported at a meeting of the Medical Association of the Greater City of New York, March, 1904. She continued to improve until July, 1904, when the treatment was stopped on account of domestic difficulties. During the following winter there was a gradual return of the original condition, but she did not again come under x-ray or electric treatment and died in May, 1905. She did better while under treatment than she could possibly have done otherwise and might perhaps have been cured if the treatment had been continued.

Favorable results have been obtained by Barnum[1] by the use of the x-ray, rather a high vacuum, and high-frequency currents from an autocondensation couch. This latter part of the treatment consists in a twenty-minute rest in a reclining chair or couch which is in circuit with the machine. No direct connection is made with the patient and no sensation is experienced. He describes the effects as an immediate rise of temperature of at least 1° F. during the time of treatment and a sense of exhilaration lasting for twenty-four to seventy-two hours. He uses an unusally powerful high-frequency apparatus consisting of very large Leyden jars and an Oudin resonator, 12 inches in diameter and 3 feet high, and regularly applies from 2000 to 3000 milliamperes. Some of his cases were apparently cured. The treatment was carried on in connection with tent-life in Los Angeles, California.

High-frequency Currents in Diseases of the Larynx.—*Tuberculosis of the larynx* is a disease in which high-frequency currents and the x-ray afford relief with a possibility of cure. The method of application has been described in the preceding paragraphs.

Cancer of the larynx is favorably influenced by high-frequency currents in conjunction with the x-ray applied in the same way as for tuberculosis. In a general way the effect of the x-ray is alterative: that of the high-frequency current eliminative. The x-ray causes molecular death of a neoplasm and high-frequency currents cause the rapid removal of the waste products.

Chronic Laryngitis.—Here the indication is for the vacuum electrode or the effluve over the outer surface of the throat. A vacuum electrode of ball shape should be used which will secure some spark-effect even with the electrode in good contact with the skin; and the current should be about 100 milliamperes.

High-frequency Currents in Diseases of the Stomach and Intestines.—*Atony of the Stomach with or without dilatation* is promptly and favorably influenced by high-frequency currents. Such a case was that of a retired naval officer who was invalided home from the Philippines during the Spanish-American War with the nervous breakdown which affected so many of our officers there. In his case the trouble was chiefly gastric, and all these seven years or so he had suffered from morn-

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[1] Archives of Physiologic Therapy, August, 1905.

ing vomiting and abdominal pain. These symptoms had become worse of late and when he came for electric treatment he was unable to keep anything on his stomach, and the question arose as to whether any malignant trouble was developing. After a test meal an examination was made by Dr. Kemp, the gastro-intestinal specialist. He found that the stomach extended to 2 inches above the umbilicus and that, therefore, there was no dilatation. Atony was evidenced by marked splashing. Free hydrochloric acid, 20; combined hydrochloric acid, 35; total acidity, 60. Some lactic-acid fermentation. The patient was placed upon the usual medicinal treatment for such a condition: resorcin, hydrochloric acid, nux vomica, and cinchona; and peptonoids in place of his customary whisky. The electric treatment consisted in the application of a vacuum electrode over the stomach and adjacent regions for ten minutes with a current of 150 amperes and without spark-effect; this being followed by the same application along both sides of the spine from the upper to the lower limits of the scapula. In this region some spark-effect was cautiously applied. It had to be slight because of the tendency of the skin to become covered with fine red spots. The high-frequency currents were begun about seven or eight days before it was convenient for him to begin taking the medicine. Improvement began immediately and he did not have a single attack of vomiting after the electric treatment was begun. During the course of the treatment, which lasted two months, he did not have a single one of the frequent attacks of vomiting and pain which used to incapacitate him for a day at frequent intervals. Quite early in the treatment he was rejoiced to find that he could brush his teeth before breakfast without being nauseated. He was apparently entirely cured at the end of the course of treatment.

Constipation may often be cured by treatment with high-frequency currents, as in the case of a young lady who had been operated on for hemorrhoids. The constipation which originally brought on the trouble was not relieved by the operation and did not yield to ordinary medicinal treatment. The electric treatment was given by means of a glass vacuum electrode whose conducting cord was connected directly with one pole of an *x*-ray coil. A primary current of about 3 amperes was used with a Caldwell-Simon interrupter. The electrode was passed all over the abdomen and some contraction was visible as first one and then another muscular mass was influenced hy the current. Given in this way it is desirable to avoid a spark-effect, and if a strong current is used decided muscular contractions may be produced. The result of a few weeks' treatment was a cure which has continued for the two years which have elapsed since that time. Similar results have been reported by Fleig and Fränkel.[1] High-frequency currents are so easily applied and with the proper equipment so readily measured and controlled that they may occasionally be tried in a case in which the combined galvanic and faradic current might possibly be better. Nothing but benefit is to be expected from the high-frequency currents, however, and if they are not effective a change may be made to the other form.

A certain number of cases depend upon a spastic condition of the sphincter ani, and for these a rectal vacuum electrode from either the

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[1] Arch. Gen. Fran. de Therapeutique Physique; Arch. of the Röntgen Ray, June, 1908, p. 32.

d'Arsonval transformer or the lower pole of the Oudin resonator is held in the rectum while a current of 150 milliamperes is allowed to flow through it for three, four, or five minutes. It is necessary to stop occasionally to allow the electrode to cool off. Suitable electrodes are made with an insulated stem.

Colitis.—High-frequency currents are almost a specific in this condition. The first report to be made upon the subject was by the present author,[1] and since that time he has treated many cases, of which two may be cited as examples. One patient was a large, strong young woman who had suffered from colitis for four years in spite of medicinal treatment by her brother who has for many years been a prominent Board of Health physician. The trouble was always worse in the summer, and during the summer of 1903 it had assumed a dysenteric character. She had twenty-five bloody movements a day for a whole month. The medicine, whatever it may have been before, was changed to opium and catechu, and an electric treatment was given at 6:30 that evening. She passed a comfortable night and the following day had only one movement. Ten treatments were given during the next three weeks and resulted in an entire cure, from which there has been no relapse during the four years that have ensued. The treatment employed in this case was a combination of the x-ray and vibratory currents. A tube of moderately high penetration was used, rays about No. 6 Benoist, with the anticathode at a distance of about 12 inches from the bare surface of the abdomen. An 8-inch Ruhmkorff coil was used with a Caldwell-Simon interrupter, a primary current of about 3 amperes, and an exposure of four or five minutes. This was followed by the application of a glass vacuum electrode all over the surface of the abdomen, but especially over two or three painful spots. The conducting cord was attached directly to one pole of the x-ray coil. As little spark-effect was produced as possible.

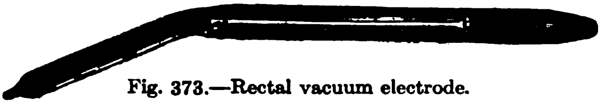
Fig. 373.—Rectal vacuum electrode.

The other case is typic of a more numerous class. The patient is of a highly neurotic type and has had many things to worry and excite her. Before coming under treatment she had for a number of years been almost daily passing a large gelatinous mass, which looked as if it could be straightened out into a thick cord or ribbon or tube many yards in length. It looked like some new and strange kind of worm. As the patient had a marked family history of tuberculosis a pathologic examination was made, the report being that the discharge contained essentially mucus and granular epithelial detritus. There was always severe abdominal pain preceding these movements. Reliance was placed upon the x-ray and a vibratory current given in the same way as for the other case. A cure was promptly brought about and for the last two or three years there has been no tendency to a permanent return of the trouble. When she gets terribly excited, however, there are attacks of the same nature lasting for one or two days. If she is in the city and receives a treatment the pain is immediately relieved and the

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[1] Radiotherapy in Enteritis and Colitis, New York Medical Journal, July 11, 1903.

attack brought to an end. The subsequent occasional single treatments have been by vibratory currents alone through the vacuum electrode. The benefit produced in these cases is due as elsewhere to what can only be termed the intense vitalizing action of this current, not to any direct bactericidal effect.

Catarrhal Appendicitis.—A certain number of chronic cases in which this seems to be the condition are permanently cured by the same technic that is so effective in colitis. This has been used by the author not with a view to the avoidance of a surgical operation where that was indicated, but as the best method of treatment where an operation is not required or when it has been performed and there are still adhesions and infiltrations to be eliminated. Excellent results have been obtained when the vacuum electrode from the Oudin resonator is applied over all the affected portion of the abdomen for about twelve minutes with a current of 150 to 200 milliamperes. A good contact is desirable and the electrode should be in constant motion.

High-frequency Currents in Diseases of the Rectum.—Doumer, in 1897,[1] was the first to publish any large number of rectal cases treated by high-frequency currents, and his success was quickly corroborated by the reports of Sudnik,[2] Stembo,[3] Tschdanow,[4] and more recently by Bilinkin[5] and Marque.[6] Hundreds of cases have been reported altogether and fairly accurate conclusions may be drawn from them.

Fissure of the anus is in about one-half the cases cured by from three to nine applications and there is prompt disappearance of the accompanying spasm of the sphincter. Other cases require many more treatments and some do not get well till the sphincter is stretched.

Hemorrhoids.—Simple vascular masses of recent development show about 50 per cent. of complete cures and decided benefit in almost all the others. The number of applications is from four to eleven. Internal and external vascular masses with occasional acute exacerbations, but without hypertrophic changes, are almost always greatly benefited and one-third of the cases are completely cured.

In all the above cases the accompanying constipation is usually cured at the same time as the local lesion.

Chronic Hemorrhoids with Thickening and Irritability of the Folds of Skin, but Without Marked Venous Congestion.—None of these cases have been entirely cured, but all are improved in seven to fifteen treatments, and 50 per cent. are very greatly benefited.

Large Venous Hemorrhoidal Masses, External and Internal.—Bilinkin treated 16 cases, giving twelve to thirty applications, with amelioration in 7 cases and failure in 9 cases. Two of these 16 cases were recurrences after operation and almost all were long-standing cases complicated by chronic gastro-intestinal disorders. In such cases electricity applied locally does not give better results than other non-operative forms of treatment. Success could doubtless be obtained, however, by a long course of treatment in which, according to my own view, the local treatment should be supplemented by the application of high-frequency currents, the galvanofaradic current, or the sinusoidal

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[1] Ann. d'Electrobiologie.

[2] Ibid., 1899.

[3] Dentra. Med. Woch., No. 8, 1902.

[4] Botkin's Hospital Zeitung, No. 30, 1900.

[5] The Lancet, July 2, 1904.

[6] Bulletin Officiel de la Societe Française d'Elec. Med., Nov., 1904.

current over the abdomen and perhaps to the corresponding spinal centers. The treatment thus directed to the cause of the trouble would be of the greatest value also in cases which were operated upon and might be used either before or after the operation.

Postobstetric Hemorrhoids (Prolapse with Weakness of the Sphincter).—Bilinkin treated 6 cases, eight to nineteen applications, 4 were cured, 2 much improved; in every case the general tonic effect was very great.

Contraindications to High-frequency Currents in Hemorrhoids.—The bad results in exceptional cases are an increase in swelling, considerable pain, and some hemorrhage; in others an acute exacerbation of the condition. When this takes place this line of treatment had better be abandoned.[1]

Thermopenetration is a method of treating hemorrhoids, which is considered in the separate section devoted to that form of high-frequency application.

Pruritus Ani with Moist Eczema.—Bilinkin treated 15 cases, four to seven applications, with a cure in every case. The present author, however, has encountered certain cases of pruritus ani which would not yield to this or any other form of treatment, operative or nonoperative, local or general, except the *x*-ray, which seems to be a specific. There is nothing magic about the high-frequency currents, though they are very effective in most cases of rectal disease.

Paralysis of the Sphincter Ani.—The most difficult cases to cure are those resulting from overstretching in the operation for hemorrhoids or fissure. One such patient who was treated by the author had been operated on for ulcers of the rectum by one of the foremost rectal surgeons. The case had been one of spasmodic stricture of the urethra or spasm of the sphincter vesicæ, and the patient, a man under forty, had frequently been entirely unable to urinate. After waiting a few hours he could do so. A stricture of large caliber was diagnosed and he was operated on. There was temporary relief from the retention of urine, but on the return of the trouble the ulcers in the rectum were discovered and were regarded as having in a reflex way produced the difficulty of micturition. The operation had consisted in stretching the sphincter ani and applying a Paquelin thermocautery to the ulcerated surface. This was of temporary benefit as far as urination was concerned, but it resulted in a relaxed condition of the anus and paralysis of the sphincter. For two whole years the patient had to wear a sort of plug made of cotton and on many different occasions soiled his underwear through his inability to restrain a movement for a minute after the desire was felt. He had to regulate his diet so as to avoid soft movements, which were especially liable to cause trouble. There was a return of the difficulty of micturition and a development of absolute impotence, no erectile power remaining at all. A No. 36 (French) sound could be passed into the bladder. There was a certain amount of ulceration in the rectum. Treatment consisted in the occasional passage of a No. 36 sound and the application of high-frequency currents in the rectum, over the genitals, and along the spine. About fifteen treatments were given. The impotence was cured and his wife became pregnant. The anus lost its relaxed look and he ceased to be troubled by incontinence of feces, although the sphincter did not regain its full

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[1] Ronneaux, Annals d'Electrobiologie, Sept., 1906.

power. He became able to urinate whenever he wished to. The rectal ulcers healed. From this condition there has been very little backsliding during the year that has elapsed since the course of treatment was finished.

Fistula has been reported by Doumer as cured by high-frequency currents in several different patients, and the method is certainly worth a trial when an operation is undesirable for any reason. The cases in which it is most likely to be successful are those in which there is no apparent reason why the sinus will not heal. The cases with extensive undermining and multiple tracts are not so promising, though high-frequency currents as a resolvent would be a valuable adjunct to surgery.

Ulcer and *stricture of the rectum* are benefited by high-frequency currents, but perhaps not as much as by the galvanic current, with or without copper electrolysis.

A glass vacuum electrode with an insulated stem of the type illustrated on page 561 is introduced into the rectum and its tip pressed into the narrowed lumen. A current of 150 milliamperes from the Oudin or the d'Arsonval is applied for ten minutes every other day. The current should be turned off at intervals to allow the tube to cool. A successful case has been reported by Crane,[1] in which the trouble appeared to be cancerous. He concludes that it was not malignant because it yielded completely to the treatment.

The *method of application* in all these rectal diseases may be by a metallic rectal electrode connected with a d'Arsonval transformer and a very heavy current; 300 to 450 milliamperes may be applied without any sensation except of mild warmth; or a glass vacuum electrode connected with the upper pole of an Oudin resonator may be used. It is desirable that this should have an insulated stem and that it should be exhausted to quite a high degree of vacuum. This means a higher degree of vacuum than is present when the tube gives a rich lavender colored light, the light being, on the contrary, a steel blue or gray. And when the current is turned in the right direction, so that with the d'Arsonval transformer the glass electrode connected with what may be termed the cathodal or negative pole of the coil a decided admixture of the yellowish green (indicating the impact of cathode rays and giving origin to *x*-rays) is visible. As a rule, vacuum electrodes are used only with Tesla and Oudin currents and metal electrodes with d'Arsonval currents. According to Bilinkin, the latter is more agreeable to the patient and more effective. The shape of the electrodes, whether conic or practically cylindric, is not important. They should be of such a size and shape that they can be introduced readily and that they will make a good contact with the entire mucous membrane of the part of the rectum in which they are placed. When vacuum electrodes are used the current ought to be 125 to 150 milliamperes and the time of application from five to fifteen minutes. The electrode is not moved about, but it is necessary to stop several times to prevent it from getting uncomfortably hot. With a metallic electrode the current may be stronger (200 to 450 milliamperes) and the time of application is about the same. The author's special handle (Fig. 354, page 539) for the vacuum electrodes is completely insulated, the metal socket into which the glass electrode screws being protected by an extension of the hard-rubber

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[1] Fort Wayne Medical Journal Magazine, March, 1905.

handle 1 inch beyond the metal. The patient cannot receive a current from contact with any part of the appliance except the glass electrode. This is more necessary in the case of the different cavities of the body than when applying the electrodes to some convex surface, but when one considers how disagreeable the sparks from any exposed metallic part of the handle would be, it is easy to see why the fully protected handle is preferred in practically all cases.

The patient may be (1) in a dorsal position with the thighs vertical and the legs supported by crutches attached to the table at 12 to 14 inches above its level; or (2) he may lie upon his side in the Sims gynecologic position; or (3) he may lie upon his back with legs and thighs both flexed, feet crossed, and knees far apart. The first position is always to be preferred unless there is some reason for not using it. It gives access to the rectum, buttocks, thighs, and genital and hypogastric regions. Any of the regular operating or examining tables may be provided with the proper crutches for this position. The ordinary stirrups attached to a gynecologic table are unsatisfactory for electrotherapy about the rectum. The position they give is an extremely uncomfortable one, which no patient should be compelled to endure for a quarter of an hour, and the anus is not brought into view, but is down close to the table. One reason why the first position might not be selected in any individual case is that the operator might not have a table with the proper crutches. Another reason might be that the patient is a young woman requiring only a rectal application and the Sims position would be preferable because of the less exposure.

It is important when using a unipolar electrode connected directly with one pole of the *x*-ray coil to prevent contact between the patient and any metallic parts of the table. The top of the crutches may be protected by throwing a folded piece of rubber sheeting over them.

High-frequency Currents in Diseases of the Mouth.—*Riggs' Disease, or Pyorrhea Alveolaris.*—This is a disease which is often fatal to the tooth which it attacks. The symptoms are pain and tenderness and sensitiveness to heat and cold. An English medical man who suffered from it said that he had to warm his beer and cool his tea. The gum about the affected tooth is red and swollen and may be ulcerated. Its margin is separated from the tooth and a pocket is produced in which black concretions are often found as hard as stone and only to be removed from the root of the tooth by the dentist's tools. Pressure upon the gum causes a drop of pus to exude from this pocket and the suppuration is so active that another drop can be expressed five minutes later. The alveolus or bony socket in which the tooth sets is partly or completely absorbed. The affected teeth become loosened and eventually drop out unless the process is arrested. The teeth themselves are more apt to be sound than to be decayed, and many of them are of ivory hardness. So much has been written about the probable causation of this disease that its determination need not be attempted here. The general condition which may be termed the uric-acid diathesis has been said to be the cause of the trouble. By others it is attributed to a local infection, most probably by a variety of yeast fungus. The present author has treated a large number of these cases and has studied the reports of cases treated elsewhere, and it does not seem probable that it is due to any single specific cause. The etiology seems to present more or less analogy to that of chronic ulcers of the legs. Go into any clinic and look at these poor leg cases and you will see fat and thin, anemic and plethoric, people with varicose veins, but a greater number without them, men and women. There is only one striking fact about them, and that is that the percentage of chronic ulcers of the leg among clinic cases is many times greater than in private practice. Of course, the leg is exposed to injury and its circulation is peculiarly liable to interference, but the constitutional condition which causes an ulcer to develop and remain open for half a lifetime must be brought about in many different ways. Similarly, in a case of Riggs' disease, there may be found some definite constitutional condition, like uric acid, diabetes, or anemia, which should be remedied. More often, however, the cause is indefinite and the best that can be done constitutionally is to recommend fresh air, exercise, suitable diet, and possibly tonics. Locally, the services of the dentist should precede those of the electrotherapeutist. All the stony deposits should be scraped away and an application such as peroxid of hydrogen, glacial acetic acid properly diluted, trichloracetic acid properly diluted, nitrate of silver of the proper strength, or tincture of iodin.

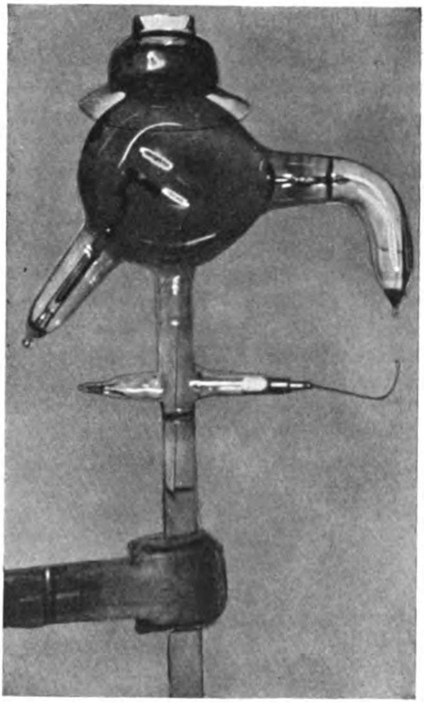

Fig. 374.—Tousey's *x*-ray tube arranged for the treatment of pyorrhea alveolaris.

The electric application which the author has found successful in cases of pyorrhea alveolaris is a combination of the *x*-ray and high-frequency currents. For these cases an ordinary *x*-ray tube, such as a 50-cm. heavy target Müller tube, is encased in a localizing shield having a 2½-inch opening. The rays should be about No. 4 of the Walter or of the Benoist scale, the resistance equal to a parallel spark of about 2 inches, the primary current about 3 amperes, with a 12-inch coil and Wehnelt interrupter and a current of 1 or 2 milliamperes passing through the *x*-ray tube. The anticathode of the tube is about 10 inches from the face, the lips are open, exposing the teeth and gums, and the time of exposure is from one to two minutes. Treatments are given twice a week and are so regulated as to produce no redness of the skin and no falling out of the moustache. A special *x*-ray tube may be used which is made entirely of lead glass except at the end of a prolongation to be applied directly to the gums. The tube has an insulated handle and is held in position by the hand. It is necessary to have conducting cords so completely insulated as not to give a spark to patient or operator if accidentally touched. These are made of light weight and are a great convenience in other cases besides this particular one. The tube lights up with a blue radiance, showing the usual line of demarcation between the light and dark hemispheres, when the current is of the right polarity. No x-ray escapes from the tube, however, except at the end of the prolongation; and the piece of ordinary glass present at this point shows the ordinary yellowish radiance of an x-ray tube. The time of exposure is about the same with this tube in contact with the gums as with the regular x-ray tube at the usual distance because the strength of application is about one-eighth as great as with an ordinary x-ray tube. In use this tube will stand only a very moderate current for two reasons: first, that from its small size it heats up readily, and second, that its resistance is much less than that of an ordinary x-ray tube, and with the same adjustment of the x-ray coil this tube will transmit 4 or 5 milliamperes while the ordinary tube will transmit only 1 or 2 with the same degree of vacuum. This latter fact contributes very largely to the rapid overheating of the tube. The tube should not be run much more than half a minute continuously, and then should be allowed to cool. The redness of the anticathode furnishes the guide to this.

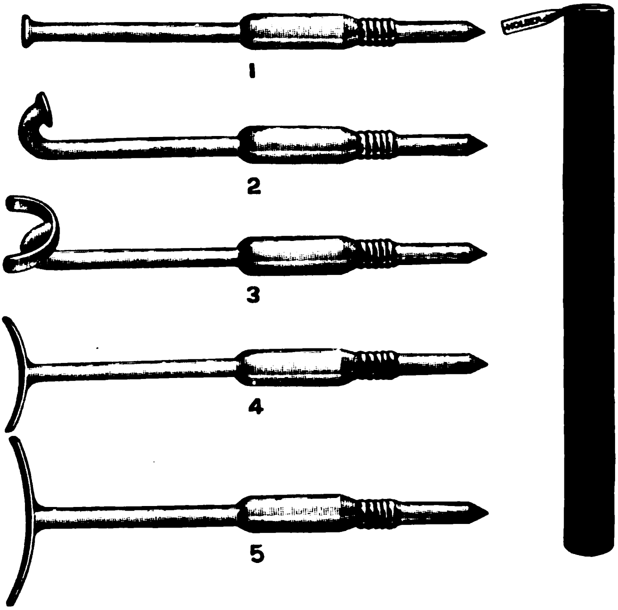

Fig. 375.—Electrodes for applying high-frequency currents to the gums in pyorrhea.

Immediately after the x-ray treatment the high-frequency currents are applied by means of vacuum electrodes placed in direct contact with the gums. These are made with an insulated stem with double glass walls, so that the lips receive none of the current, and this also enables the patient to hold the electrode. For this purpose a very light conducting cord is attached to the electrode by a light clamp. The electrodes are made in different shapes for application to lingual or buccal aspect of the gums (Fig. 375). The proper strength of current is about 75 milliamperes. The electrode is held against one part of the gums for thirty seconds and then changed to some other part. It is not kept in motion as is necessary with the stronger applications that are made upon the surface of the body. The application is entirely painless. The moment the current is turned on a strong taste of ozone or of nitrogen pentoxid is noticed.

This combined method of treatment is given three times a week. The results are very prompt relief of pain and improvement in the ulceration, so that in three weeks the dentist almost always reports that the teeth are better than for six months previously. The teeth gradually tighten up and the tenderness disappears. At about this time the trouble seems to have been narrowed down to one or two teeth and these are not at all bad. Just at this stage the patient is only too apt to consider himself practically well and to discontinue treatment. This is a grave error and is sometimes followed by a return of the trouble. The cases in which the results are most brilliant are those with ragged looking ulceration of the gums. Those which appear to be susceptible of only a moderate amount of benefit are those with rather a clean gingival border, but with a pale cartilaginous appearance, looking as if the gums would not bleed if cut with a knife. These cases are often dependent on anemia and the indication is for fresh air, exercise, and tonics rather than for local applications. It appears probable that many of the cases of this disease can be permanently cured and the teeth saved by this treatment combined with proper care by the dentist.

Action of the x-Ray in Pyorrhea Alveolaris.—The author has many times seen positive results in the cure of cases which had resisted the usual treatment by the dentist, so that his confidence is not shaken by the theoretic objections which he has heard urged against it. Thus, it has been said that the *x*-ray is filtered, and so altered in character by passing through the soft and bony tissues as no longer to produce the effect which it might if the lesion were in the superficial tissues. The answer to this argument is that a profound effect takes place in the treatment of leukemia by *x*-radiation of the marrow of the long bones through the skin and flesh and bone. If the blood-forming cells in the bone-marrow can be so affected as to produce a radical change in the constitution of the entire blood in the body, it is easy to comprehend that such a radiation can produce an effect upon the cells lining the alveoli, and experience has abundantly proved that this effect is a beneficial one.

High-frequency Currents in Diseases of the Eye.—*Trachoma,* or granular lids, has been treated successfully by a combination of the *x*-ray and high-frequency currents.[1] A vacuum electrode was applied to both the inner and outer surfaces of the lids for about three minutes three times a week. A current of about 50 milliamperes without spark-effect is suitable. A cure was effected in 18 cases, the time required being from three weeks to three months. There are probably better methods of treatment for this affection.

Atrophy of the optic nerve is a disease in which the author suggests the use of high-frequency currents. A current of 150 milliamperes would be applied to the temple by a glass vacuum electrode, only a loose contact being made with the skin in order to produce a slight spark-effect. The electrode would be kept in motion and after five or ten minutes over the temple a milder application of 75 milliamperes would be made over the closed eyelids.

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[1] Geyser, Journal of Advanced Therapeutics, New York, May, 1904.

Paralysis of the ocular muscles has been considered under the heading of Diseases of the Nervous System.

High-frequency Currents in Diseases of the Nose.—*Ozena.*—Successful cases have been reported[1] in which the crusts and the offensive odor disappeared and the mucous membrane assumed a healthier aspect. In about an equal number of cases (10) treated by other observers[2] the results have been less promising. Even in these cases there was a feeling of relief for twelve or twenty-four hours after each treatment, with less crusts, greater freedom of the nostrils, more liquid discharge, and less dryness of the throat. There was a return of the symptoms, but in the long run there was decided improvement. This consisted in a lessened production of crusts, the nasal mucus became more fluid, there was less offensive odor. Objectively, the mucous membrane appeared but little changed; the atrophy of the turbinates was about the same. The treatment is not unpleasant and, as may be seen above, even the less favorable results show appreciable improvement. Returning, however, to the successful cases, a complete cure was not obtained, but such great improvement as to get rid of the offensive symptoms.

The method of application is by means of a metal rod with an insulated handle. The part which is introduced into the nose is covered with sealing wax or hard rubber. When the current from the Oudin resonator is turned on an effluve of fine sparks escapes from the rod through the hard rubber. These fine sparks are applied to every bit of the affected mucous membrane. After a few minutes' application the electrode is removed and if the patient blows his nose all the crusts will usually come away. The application lasts about fifteen minutes and should be made every other day; 50 to 75 milliamperes is the proper strength of current. No cocain or other local anesthetic is needed.

Hay-fever.—The author suggests the use of a glass vacuum electrode, insulated by a double wall except at its extremity, which may be applied to all parts of the nasal mucosa, but especially to the inferior and middle turbinated bones. It is very easy to get a spark-effect from an electrode of this size even if the contact is pretty good; and this seems to be the indication in these cases. This vacuum electrode will give one all the benefit of the high-frequency currents combined with the influence of the ultraviolet radiation from the tube. A similar application may be made to the outer surface of the nose, at the sides halfway from the root to the tip. The strength of current for the interior of the nose is from 50 to 75 milliamperes. And for the outside a current of 75 to 125 milliamperes, applied by a somewhat larger electrode with an uninsulated stem and terminating in a ball. This shape gives the spark-effect desired in these cases.

Sinusitis.—Chronic inflammation in the frontal sinus, the ethmoid cells, and the antrum has yielded to high-frequency applications at the author's hands. A small glass vacuum electrode has been connected with the Oudin resonator and is passed over the surface of the affected parts of the face by the patient herself (Fig. 376). The strength of current is sufficient to redden the skin, but not to cause pain.

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[1] Hahn, Gazette Degli Ospedali e Delle Cliniche, March 5, 1905; and Bordier and Collet, Congrés pour l'avancement des Sciences, Montauban, 1902.

[2] Laras and Bordet, VII congrés d'otologie, in Tribune Medicale, Oct. 15, 1904.

High-frequency Currents in Diseases of the Ear.—*Tinnitus Aurium.*—The effluve from an Oudin resonator is applied by means of an electrode consisting of a bundle of fine wires surrounded by a glass cylinder. The glass can be made to project any required distance beyond the wires; the object being to secure an effluve of fine violet sparklets. This is applied to the skin behind the affected ear for three to six minutes; it is practically painless and is always easily borne. There is some redness of the skin and even a slight burn if the application has been too vigorous. The patient's sensations are not a reliable guide, as even entirely too strong an application would not be really painful. A current of about 100 milliamperes with the ends of the wires well retracted within the glass cuff would be proper for a starting-point. Fig. 366, p. 566, shows the proper electrode.

Fig. 376.—Application of high-frequency current in frontal sinusitis.

The application should be made three times a week and may be to one or both ears, according to the case. Imbert[1] has treated a large number of cases of tinnitus aurium due to a variety of causes, and found that those without antecedent suppuration were always readily

[1] Journal des Practiciens, Dec. 17, 1905.

and permanently cured. Whether the lack of success in cases due to suppurative middle-ear disease indicates absolute failure of this method in those cases or simply that they respond much more slowly is a question which has not yet been decided.

When the noises in the head are not of too long standing or too intense, improvement is usually noticed by the fifth or sixth treatment. In one severe case (Dr. Maquez) there was no improvement for a whole month, and then it was only slight and temporary, nevertheless a cure was ultimately obtained. There is then no definite time during which the treatment should be tried. The improvement which takes place is not uniformly progressive. During the course of the treatment there may be many relapses, but the noises are not so loud and they soon cease again. It is very necessary to continue the treatment for a month after the patient seems entirely cured. According to Imbert's observations, this treatment does not result in any improvement of hearing if that has been impaired. He considers the beneficial effect to be due in some cases to a revulsive action and to the reduction in arterial tension, which is one of the constitutional effects of high-frequency currents.

High-frequency currents, according to Imbert, Dénoyes, and others, constitute the best treatment for vascular tinnitus aurium. The treatment is directed to the general vascular condition and not devoted alone to local applications.

Marage reports good results from the autoconduction cage about the head and shoulders, and vibration applied to the temporoparietal region.

Skin Diseases.—A method which is very generally useful is by the application of an effluve from the Oudin resonator, or similar high-tension high-frequency apparatus for ten or fifteen minutes, followed by the application of a few sparks from a lower tension apparatus. The latter effect may be obtained by having the patient hold a metallic electrode connected with the lower terminal of the Oudin resonator, and drawing a few sparks from the affected part of the body by means of the operator's hand or a damp sponge. A metal key or coin will do this effectively, but less agreeably to the patient. All the different skin lesions referred to as amenable to static electricity yield still more readily to high-frequency currents.

Some special applications may be mentioned: Telangiectatic redness of the nose may be treated by the effluve or sparks from the Oudin resonator, or by the application of a condenser electrode and d'Arsonval currents. The same applications are useful for *lupus vulgaris* and *erythematodes.* The effluve is valuable in *acne*, *impetigo*, *herpes zoster*, *furunculosis*, and *sycosis*. Alopecia sometimes yields to the effluve, but more often requires sparks.

The application of high-frequency sparks of different strengths is a wonderful resource in epithelioma and in carcinoma and lupus.

Freund and Fabrozzi[1] find that high-frequency sparks applied to the normal skin produce inflammation of the most superficial layers, great dilatation of the veins, extravasations of blood, and vacuolization of the walls of the arteries. There may be destruction of the entire epithelial layer. Oudin regards these results as partly due to the ultraviolet radiations which accompany the production of these sparks.

Warts, small epitheliomata, and *moles* may be destroyed by the use

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[1] Annali di elletricita medica, 1903, No. 11.

of high-frequency currents as a cauterizing agent. For this purpose a metal electrode or small glass vacuum electrode is held upon the spot to be treated and a current of 150 milliamperes is sent through it by the Oudin resonator or the d'Arsonval transformer for ten or twenty seconds. Histologic investigations by Arienzo and Fabrozzi[1] show that the epithelial elements of the skin are most powerfully influenced, active hyperemic changes taking place in the surrounding area, with exfoliating scabs as an end-product. The repair of the lesions produced by the treatment takes place by a process of leukocytosis and phagocytosis in the subcutaneous tissues, resulting in the complete regeneration of the epithelial strata of the skin. The resulting cicatrix is preferable to that produced by the operation of chemic caustics or excision and the application is comparatively painless.

Fig. 377.—Flat warty area cured by high-frequency sparks.

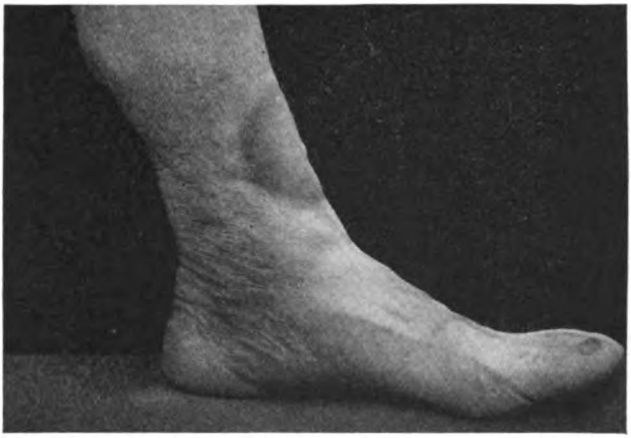

Fig. 378.—Another view of the same case as Fig. 377.

Figs. 377–379 show an extreme case treated by the author. There

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[1] Jour. Advanced Therap., April, 1904.

was a flat warty surface almost surrounding the leg near the man's ankle. It had existed for about two years in spite of medicinal applications. A shower of long white sparks was applied at different points over the entire surface, not long enough at one place to produce necrosis.

Fig. 379.—Another view of the same case as Fig. 377.

Fig. 380.—Cavernous endothelioma of face cured by high-frequency sparks.

Each treatment was followed by visible improvement and in a few weeks the surface had become normal.

Fig. 380 shows a cavernous epithelioma or endothelioma of the face which resisted *x*-ray treatment and which was completely destroyed by a single application of sparks from a metallic electrode connected with one pole of the resonator.

Fig. 381 is of a case of flat, scaly, pigmented keratosis, apparently threatening to become epithelioma, which made such slow progress under *x*-ray treatment that a single application of high-frequency sparks was made with complete removal of the lesion.

Fig. 381.—Pigmented keratosis of face cured by high-frequency sparks.

The author's high-frequency spark electrode and special technic are important unless the patient is under a general anesthetic.

They render the application painless (see p. 543).

These are practically the only cases in which an irritative effect is to be desired. Usually the application of high-frequency currents is so made that even with very strong currents no irritation of the skin is produced. This is generally accomplished by maintaining a good contact with the skin and by keeping the vacuum electrode in constant motion. Unipolar applications of 250 milliamperes may be given if necessary without irritation. If, for any reason, it is necessary or desirable to make the application through the clothes or bandages, the electrode should be pressed quite firmly, it should be kept in motion, the current should be moderate, not over 150 milliamperes, and the adjustment of the whole high-frequency apparatus should be such as to give volume of current rather than tension. This difference manifests itself in the one case by simple warmth when the electrode is in contact with the skin, while when the apparatus is adjusted for tension there are disagreeable sparks passing down from the outer surface of the vacuum tube even when the latter is in good contact with the skin. Increase in tension is produced principally by lengthening the spark-gap between the Leyden jars. The volume of current is increased by using greater self-induction in the primary coil, arranging the interrupter so as to give rapid interruptions and a strong current, and using a large number of turns in what may be termed the primary part of the Oudin resonator or the d'Arsonval transformer. It is also increased by the use of vacuum electrodes having leading-in wires; and especially by the use of metallic electrodes. The effluve is increased by a combination of the elements which increase both tension and volume.

Acne is benefited by the local application of high-frequency currents, either the effluve or by a vacuum electrode. The latter is more useful. The electrode should be dome shaped and at least 1 inch in diameter, the flat surface being applied to the skin. The use of talcum powder is desirable to secure a good contact while the electrode is kept in rapid motion. A current of about 100 milliamperes should pass through the glass electrode for about ten minutes and sparking should be avoided. The applications should be made three times a week. The beneficial effect is largely due to simple stimulation, but there is also a germicidal effect from the ozone generated in the tissues by electrolysis and from the ultraviolet ray produced around the vacuum tube. The electrodes best adapted to almost all high-frequency applications are those which produce the greatest amount of ultraviolet light. Its presence is demonstrated by Willemite, the same mineral that is used as a test for radium rays. The *x*-ray and high-frequency currents may be combined in the treatment of these cases. It is easier to get a permanent cure in these cases by using in addition to the electrotherapy the author's treatment by tar-soap friction, zinc and salicylic ointment, and rhubarb and soda internally. This is given in detail on p. 980. Treatment by incision and curetting is to be avoided. It often results in the most frightful scarring. Success may be confidently expected in these cases, but it requires months of treatment. Special sources of reflex irritation like phimosis should be remedied.

Alopecia.—The application of a vacuum electrode carrying a current of 100 to 150 milliamperes is an excellent stimulant to the hair-follicles and is a very convenient form of treatment. The prognosis varies in different cases. In ordinary cases of a tendency to baldness high-frequency currents are used alone, but in alopecia areata the *x*-ray is required as an adjuvant.

Treatment of Alopecia Areata by High-frequency Sparks.—Bordier, Bordet, and others have reported successful cases. Bordier's technic employs for recent mild cases an Oudin spark electrode with a glass sleeve. This is connected with one pole of a large d'Arsonval transformer, the other pole of which is grounded. A shower of tiny painless sparks are applied in this way over one part after another, long enough in each place to produce intense redness, but not vesication. It requires only a few seconds in each place. Bordet[1] cured a case which had resisted all sorts of treatment, including the above technic. He applied the same fine sparks for twenty or thirty seconds at a time in each place. The entire scalp became very red and the fifteen or twenty separate places to which the sparks had been applied until the skin

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[1] Arch. d'electricite medicale, Sept. 25, 1907.

turned white each time became blistered. This latter condition was succeeded in a day or two by thick crusts, sometimes moist, resting on an indurated and very congested base. It took fifteen days for a very superficial slough to separate, leaving a superficial, flexible, pink cicatrix which became brownish about the thirtieth day. This was followed by the appearance of fine hairs. The treatment, which was a painful one, was repeated every eight days until two-thirds of the hairy scalp had been vesicated in this way. The hair was completely restored in about nine months.

A case now under treatment by the author is shown in Fig. 382. A glass vacuum electrode connected with the Oudin resonator is lightly rubbed over the bald areas with as considerable spark effect as can be borne without much discomfort. This treatment causes redness of the scalp, but no blisters or scabs. The same treatment may be applied so as to produce the more severe effect above described if the vacuum electrode is held at a little distance from the surface and a shower of tiny sparks is allowed to fall upon the same spot for twenty for thirty seconds.


Fig. 382.—A case of alopecia areata now under treatment by high-frequency currents.

Chilblains are benefited by the analgesic and vasomotor tonic effect of the high-frequency currents. A vacuum electrode is used with a current of about 100 milliamperes.[1]

Eczema in practically every form is benefited by the application of high-frequency currents. A local application of the effluve or by vacuum electrodes is usually best. This should not be confined to the region of the lesion, but should extend to a third of the surface of the body. For instance, for eczema of the legs the application should be made to the whole of both lower extremities. The vacuum electrodes should be applied over smooth dry bandages or underclothes. A current of 50 to 75 milliamperes with scarcely any sparking effect even through the clothes is applied directly over an acute eczema, while about 150 milliamperes with as little sparking as possible is applied over the unaffected skin. The applications should last about fifteen minutes, during which the electrode is kept in constant motion; and should be made three times a week. As the case improves, stronger applications

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[1] A most valuable medicinal application consists in soaking the feet for ten or fifteen minutes in mackerel brine as hot as can be borne. This may have to be repeated two nights afterward. These two applications will very often give relief for the entire winter.

are made over the lesion. The benefit is due partly to the local effect, but very largely also to a systemic effect, by which all the processes of metabolism are stimulated and the condition of suboxidation which causes so many of these cases is remedied. There are certain cases in which the skin of the whole of both lower extremities is thickened, indurated, and brownish red. This is accompanied by annoying pruritus and seems to be caused by the uric-acid diathesis. High-frequency currents produce a favorable effect applied locally or generally.[1]

Furuncles are favorably influenced by the local application of high-frequency currents; vacuum electrode, 100 milliamperes for ten minutes, with the electrode moving over the entire region. Sometimes they are aborted; sometimes made to heal more rapidly after incision. This is the case also with felons and cellulitis; the current having an indirect bactericidal effect. A local application of high-frequency currents immediately before an operation for cellulitis or abscess acts as a local anesthetic.

Herpes zoster, with its half-girdle of eruption and severe pain and its subsequent depression of all the vital forces, is successfully treated in this way. There is perhaps no better analgesic in zoster and intercostal neuralgia than the application of high-frequency currents of 100 milliamperes by vacuum electrodes. And if the application is made not only along the course of the nerve but also along the spine and over the abdomen, the disappearance of the eruption and the improvement in the general condition are very prompt. Herpes in other regions and of other types rarely requires this treatment and generally there is some underlying cause whose treatment is more important than that of the cutaneous lesion.

Impetigo, again, is a disease favorably influenced by the local application of high-frequency currents freely over all the affected regions; 100 milliamperes is the proper strength of current with the Oudin resonator and glass vacuum electrodes with leading-in wires.

Indurated cicatrices yield to treatment by high-frequency currents; vacuum electrode 100 milliamperes for about five minutes three times a week, keeping the electrode in motion. The *x*-ray has the same effect of causing the disappearance of the induration by a process of absorption and the two methods of treatment may be combined. Each session would consist of a mild application of the *x*-ray followed by the use of the vacuum electrode.

Keloid has been treated by the *x*-ray and high-frequency currents and often successfully.

Keloids may sometimes be made to disappear and remain away by applications of a high-frequency high-tension electrode, at first directly in contact and then slightly separated, so as to produce a shower of short sparks distributed over the surface. A sort of crust is produced which falls off in a week or so. Thirty or forty treatments are required to effect a cure. A case of widespreading keloid of the interscapular region was treated in this way at St. Bartholomew's Clinic and returned a year later completely cured.

Keloid appears to the author to be so distinctly due to a constitu-

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[1] As medicinal agents in these cases the best effects are obtained from boric acid ointment externally and two 5-grain tablets of salophen three or four times a day internally. The latter is entirely innocuous and may be taken for a number of months even by the most delicate old lady.

tional tendency that local applications are as likely to result in disappointment as are surgical operations unless accompanied by systemic treatment. Thiosinamin,[1] a drug introduced by the author in 1894 for the treatment of this diathesis, has given good results when combined with these or other local applications. It may be given internally in a 3-grain capsule every night just before getting into bed, and should be taken more or less continuously for six months or so.

Lupus Erythematosus.—A large number of cases have been treated by Bissérie, Jacot, and others, with a complete cure in over 50 per cent. The application is a local one, either by the effluve or by means of vacuum electrodes. In the latter case a current of about 100 milliamperes should pass through the electrode for about ten minutes, the electrode being kept in motion. There are cases which sometimes do not yield to *x*-ray or ultraviolet ray treatment, but in lupus vulgaris either of these methods seems preferable to the treatment by high-frequency currents.

Molluscum contagiosum is one of the diseases in which a cure has been reported from the local application of high-frequency currents (glass vacuum electrodes with a current of 100 milliamperes).

Pruritus.—For this symptom in almost any locality high-frequency currents are almost a specific. Pruritus ani is considered under the head of Rectal Diseases. Elsewhere the application should be by the effluve, taking care not to give many actual sparks, or by the vacuum electrode. In the latter case there should be a good contact with the skin, facilitated by the use of powder, the current should produce very decided warmth with hardly any sparking, about 150 milliamperes. Relief is usually apparent at once. The production of a slight rash like "prickly heat" by high-frequency treatment is usually unnecessary and in this case would be quite undesirable.

Psoriasis yields to high-frequency treatment just as it does to so many other stimulating local applications, and some cases have been reported where the results appeared to be permanent. The effluve or the glass vacuum electrode is applied over the different lesions with a strength of 75 to 100 milliamperes and some slight spark-effect cautiously applied. The latter had better be more of the nature of a loose contact with the skin than of sparks from an electrode held at any appreciable distance from the surface. This treatment certainly has a tonic effect upon the general system and so will probably yield a relatively greater percentage of cures than the ordinary medicinal local applications.

Seborrhea is a disease in which high-frequency currents may be used as an adjunct to other treatment or may even effect a cure by themselves. The preferable method is to have some thin dry covering over the surface and then to apply the vacuum electrodes with a current of not more than 100 milliamperes. Have very little spark-effect and keep the electrode in motion.

Here, as in psoriasis and eczema, the application is much more cleanly, agreeable, and convenient than any local medicinal application. And to the local effect is added the beneficial influence upon the system at large.

Skin-grafting.—Dr. J. Sherman Wight of Brooklyn has used the

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[1] Thiosinamin as recommended for keloid is uniformly effective in simple indurated cicatrices.

high-frequency currents in the surgical operation of Thiersch's skin-grafting. The surface of the ulcer is freshened by cutting away a very thin layer. The usual slow process of checking hemorrhage by pressure is dispensed with, the large skin-grafts being at once applied. Sparks from a high-frequency apparatus are then applied to arrest hemorrhage by causing coagulation. The pointed metallic electrode is held about ½ cm. above the surface of the graft. The grafts are said by Dr. Rushmore, another surgeon who has used the method, to adhere better and be more successful than if the electric application had not been made.

Ulcers.—Chronic ulcers anywhere and of any nature are quickly and favorably influenced by high-frequency currents. Many recommend the effluve, but as may have been noted already the author's favorite method is by rubbing a vacuum electrode over a light, dry covering. Using this method, the current should at first be less than 100 milliamperes with as little spark-effect as possible. After the ulcers are practically healed, a stronger current may be applied, and when there is no raw surface at all, 150 milliamperes will be found to have a good effect upon the swelling and induration so often present, but even then care should be taken not to have any appreciable sparking, and at the appearance of a little red punctate eruption the strength of the application should be materially reduced.

Perforating Ulcer of the Foot.—Oudin[1] treated such a case successfully with the resonator current applied through a metal probe covered with cotton wet with a solution of cocain.

Xanthoma Multiplex.—Cases of this disease have been treated successfully with the *x*-ray alone[2] and by a combination of the *x*-ray and high-frequency currents.[3] The patches treated by high-frequency currents disappeared if the application was severe enough to blister the skin, otherwise they were not affected.

In all these cases where a local action upon the skin is desired the glass vacuum electrodes seem to be the most effective. This is attributable in part to the ultraviolet ray generated by the tube. The presence of this invisible light can be readily demonstrated by the fluorescence excited in a piece of Willemite held near one of these electrodes.

High-frequency Currents in Periostitis, Cellulitis, Phlebitis, and Varicose Veins, etc.—*Periostitis.*—Bilinkin[4] gives a description of 11 cases treated by high-frequency currents; 8 of them were tubercular, and all were either cured or very much improved. The applications were by condensing electrodes, a type in which a metal rod passes down almost the full length of the hollow glass electrode, being separated from the glass wall either by a partial vacuum or by oil. The discharge from such an electrode is unusually rich in the spark element. The applications were of five minutes' duration three times a week. A case of extensive tubercular periostitis of the tibia was apparently entirely cured by twenty applications. A tubercular affection of the metacarpophalangeal joint of the thumb with entire loss of motion and

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[1] Bulletin Officiel de la Societe française. d'electrotherapie, Jan., 1911, vol. xix, No. 1, p. 1.

[2] Evans, Brit. Jour. Dermatol., 1902, p. 465.

[3] Whitehouse, Jour. Cutaneous Diseases, Oct., 1904.

[4] Bulletin Officiel de la Societe française d'electrotherapie et de radiologie, Dec., 1903, abstracted in Archives of Electrology and Radiology.

atrophy of the thenar eminence and involvement of the skin, with the formation of five sinuses, was likewise treated. Twenty séances resulted in diminution in the size of the swollen osseous extremity and the motion in all directions had begun to improve. Dr. Bilinkin observes that "in cases where the process had advanced to suppuration and sinus formation the response to treatment was quicker than where the skin was intact." This agrees with the author's view that the beneficial effect of high-frequency currents in suppurative diseases is due to their favoring the process of elimination. An Oudin resonator or a d'Arsonval transformer should be used with either vacuum electrodes or condensing electrodes, applying a current of 150 to 200 milliamperes for five or ten minutes three times a week. If the skin is broken the author prefers to make the application over dry dressings. The *x*-ray is often of service in combination with high-frequency currents in these cases.

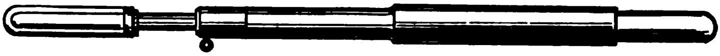

Fig. 383.—Condensing electrode for surface application.

Cellulitis and *abscess* may be very quickly disinfected after incision and caused to heal promptly. The best method of application is over a moist dressing, using a vacuum electrode from the Oudin or the d'Arsonval, and applying a current of 150 milliamperes for five minutes. Where there are sloughing tendons or other tissues which have to come away by slow process, healing cannot take place at once, but even here the application is distinctly worth while because of its analgesic and antiseptic effects.

Phlebitis and Varicose Veins.—This treatment is effective in reducing the swelling and induration remaining after an attack of phlebitis or periphlebitis. This is accomplished by its eliminative effect; and then if the treatment is continued the circulation becomes normal and the patient is saved from the consequences of such trouble—ulcer and varicose veins. In a case referred to the author by Dr. Charles McBurney the circumference of the affected leg was 1¾ inches greater than that of the sound leg. There were characteristic brownish-red spots the size of a silver dollar or twice that size. Over these the epidermis was very thin and at times there was a serous discharge. There was no varicosity as yet. The treatment by high-frequency currents (ultraviolet light the patient called it at first) was begun about a year after the first appearance of the trouble. Its first effect was to cause the entire disappearance of the cramps, which had been a painful feature of the case. The next was a change in the amount of swelling, which almost disappeared in the morning, but still recurred toward night. At the present writing the case has remained cured for two years after cessation of treatment. The swelling disappeared and the spots on the skin are normal. The treatment consisted in the application of a glass vacuum electrode, connected with the Oudin resonator, to the whole surface of the limb. Powder was used upon the skin and the electrode was kept in motion. The current was at first 150 milliamperes, and even less over the chronic inflammatory spots. Later it was gradually increased until 200 milliamperes were applied to all parts of the limb. While under the author's care the patient was taking 10 grains of salophen three times a day and applying an ointment of salicylic acid and Cheeseborough zinc-oxid ointment to the chronic patches, and an elastic stocking was worn. The treatment was given three times a week for two whole winters.

Cases with varicose veins require a very much longer time to cure and the author's belief that they can be completely cured is founded upon the marked benefit experienced in a short time by some severe cases. The technic suggested is the glass vacuum electrode with a current of 150 to 200 milliamperes from the Oudin resonator for ten minutes three times a week. Of course, an elastic stocking should be worn until a cure is effected.

DIATHERMY, OR THERMOPENETRATION

These names have been applied to the application of high-frequency currents of many hundred milliamperes or even over an ampere, generating a great deal of heat in their passage through the tissues of the human body. Their frequency must be about a million oscillations per second in order to avoid sensory and motor effects, but their voltage is relatively low; and for many purposes their currents are applied by metal electrodes, either bare or covered with wet cloth, in direct contact with the surface of the body.

Thermopenetration or Diathermy.—Nagelschmidt[1] has been chiefly instrumental in developing this line of high-frequency treatment. Essentially, it consists in the application of high-frequency currents of comparatively low voltage and great milliamperage, and very often employs two metal electrodes, with or without a covering of wet cloth and connected with the ends of a d'Arsonval coil.

The original d'Arsonval high-frequency apparatus, with two electrodes applied to the surface, generated a demonstrable amount of heat in the body.

At each Leyden jar discharge across the spark-gap a short series of exceedingly rapid oscillations was set up, which very quickly died out, just as the vibration of a guitar string may be arrested by the pressure of the hand. The currents flowed for only a small fraction of the time between successive discharges, and it was impossible to transmit a sufficient quantity of electricity through the bodily resistance without using an excessive voltage.

Three different methods are available for producing the stronger currents required for diathermy. One employs an ordinary induction coil with condensers, D'Arsonval solenoid, and a series of sometimes as many as nine very short spark-gaps. This results in a very rapid succession of discharges, each of which produces its series of damped oscillations. The apparatus is based upon the Telefunken Company's apparatus for wireless telegraphy and is very effective.

A *quenched spark* is one in which the hot gases are immediately removed and the current flow stopped, just as an ordinary arc may be blown out by a strong current of air. Spark-gaps with such a character make possible a much more rapid succession of sparks than when the conductivity of the hot gases defeats the very object of the gap. This can be done very well by having the terminals on revolving wheels, so that the hot gases are carried away mechanically and new, cool metal

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[1] F. Nagelschmidt, Lehrbuch der Diathermie, 1913.

surfaces are constantly presented. A spark-gap of this character could be used for diathermy, but the Telefunken type is simpler and sufficiently effective. Another uses a 1½ kilowatt transformer with the same series spark-gap condensers and d'Arsonval solenoid. These two methods produce damped oscillations, differing from the ordinary high-frequency currents in having lower voltage and greater milliamperage. The third method, which was the first to be employed, uses the *undamped oscillations* produced by the singing arc (page 618), but, instead of being applied directly to the patient as with the DeForest needle, the current for thermopenetration is taken from the two ends of a secondary coil which surrounds the self-inductance of the singing arc circuit. The direct electric-light current supplies a current of about 6 amperes to an arc lamp which has an inductance in shunt to it. The current becomes an oscillatory one, and the arc emits a musical note from the rapid alternation between greater and lesser expansion of the hot gases between the electrodes. The currents supplied to a patient, also in shunt, consist of undamped oscillations of a sufficient frequency, about 1,000,000 per second, and lasting a large part of the time between one stronger flow of current at the electrodes and the next. Theoretically, this seemed to solve the problem, but it was very soon found that a lack of uniformity in the operation of the arc lamp offset all the advantages of the undamped oscillations, except the quantity of electricity. Surrounding the arc with an alcohol flame improved matters somewhat, and, for certain surgical applications, this is a satisfactory method of thermopenetration, but for a constitutional effect the other apparatus is much to be preferred.

The **electrodes for diathermy** may be of bare metal when applied to some insensitive surface, with a good area of contact, as when the electrodes are held in the hands and sometimes when they are applied to opposite sides of a limb. Very often, however, it is better to cover the electrodes thickly with cloth wet through and through with a weak solution of sodium bicarbonate. Diathermal currents are also applied in autocondensation, using the same large insulated metal sheets employed with the d'Arsonval currents.

It is essential, except in autocondensation, that there shall be a good contact when the current is turned on or off and during the entire duration of its flow. Disregard of this precaution results in very hot, painful sparks.

The **effects of diathermy,** which are most important, are due to the production of heat in the tissues caused by the same ohmic or frictional resistance to the passage of a current of great milliamperage, as in the case of a flatiron heated by an electric current.

If electrodes about 2 inches in diameter are applied at opposite sides of a piece of raw meat, the latter may be cooked all the way through along a direct path between the two electrodes. Placed a little distance apart upon the same side of a piece of meat, the latter is cooked to only a certain depth between the electrodes. Applied to opposite sides of a patient's joint there should at first be no sensation; if there is, it means that the contact is imperfect, the metal not completely covered by the wet cloth, or that there is an abrasion of the skin which should be covered by adhesive plaster, or that the current is too strong, or, more often, that the cloth is not wet all the way through. After the proper current has been turned on for a very few minutes a sense of warmth, and later of intolerable heat, develops inside the joint. The stage of marked discomfort is an indication for stopping and applying the current to some other part of the joint. The best guide to the right amount of current for local use is the sensation of the patient, and one would hesitate to apply it to an unconscious person or one with sensory paralysis. It ought to feel uncomfortably hot, but not really painful. *The electrodes must be in close contact with the skin while the current is being turned on or off*, otherwise very hot, painful sparks are produced.

A thermometer may show that the temperature of the skin at the place of application is higher than the normal temperature of the blood, and animals have been killed by the application of 2300 milliamperes for an hour. There was high temperature without microscopic lesions.

The therapeutic importance of thermopenetration lies in the fact that heat is developed in the depth of the tissues, and not merely upon the surface, as with ordinary hot applications. The beneficial result is from an increased blood and lymph circulation and increased activity of tissue metabolism. Gouty deposits often disappear, sciatica and other cases of neuritis are often cured; asthma is often relieved as by no other electric means. Traumatic and inflammatory swellings and deposits are benefited. Gonorrheal rheumatism is benefited by a bactericide action of the high temperature produced inside the joint.

Nagelschmidt's autocondensation couch for diathermic currents is of wood with a metal plate under and a hard-rubber plate over it; and entirely covering the patient is a flexible sheet of metal netting with a flexible rubber covering. Schittenhelm's is like the one used by the author (page 587).

Monopolar applications of diathermic currents are made with the same condenser electrodes (glass vacuum electrodes and glass or hard rubber electrodes filled with graphite), as for ordinary high-frequency currents, and also with the same effluvers.

Bipolar applications of diathermic currents sometimes employ one or more large metal cylinders to be held by the patient, but very commonly metal plates of a nature to be somewhat moulded to the surface, still with sufficient rigidity to allow of firm pressure being exerted by a wooden handle or by a bandage. Some plate electrodes include a resistance thermometer, connected with a separate electric apparatus, which indicates the temperature attained at the place of contact with the skin. Others are made with an insulated backing, and the temperature may be determined by touching with the finger. Six thicknesses of wet gauze form a suitable covering for the electrodes. Water electrodes, like the shallow four-cell bath, are sometimes useful.

The marginal effect, which is to be avoided, is a concentration of the current when two electrodes are close together and the skin is unduly heated at the closest points.

Special Effects of Diathermy.—There is no electrolysis in the ordinary polarization sense, and the tolerance of the tissues to warmth is the only limit to the strength of the current. In transverse penetration the greatest rise of temperature occurs in the skin, less in the bone, muscle, fat, and least in nerve. In longitudinal or parallel conduction the conditions are exactly reversed. In the use of the autoconduction cage the current traversing the solenoid is measured by a hot-wire milliamperemeter, between one pole of the generator and one terminal of the solenoid. No important rise of temperature occurs in the body. A small solenoid, through which passes a high-frequency current of 10 or 12 amperes, warms an arm held inside it, and a ball of tin-foil becomes hot instantly and will melt in a few seconds. A finger-ring becomes dangerously hot.

In both autoconduction and autocondensation the therapeutic effect of diathermic currents is due to the heating of the body.

With bipolar electrodes 300 or 400 ma. or more causes arterial hyperemia of the skin with reflex stimulating effects, such as perspiration and a sense of heat. There is a sedative effect upon itching or pain and also a derivative effect, as well as a temporary increase in blood-pressure consequent upon skin irritation.

The regular bipolar diathermy produces no motor or sensory effect except that of warmth. The skin and blood and living bone are chiefly warmed. The local temperature is raised by therapeutic applications of 40° or 45° C. Higher temperatures, even 45° to 50° C., which are below the temperature of coagulation, may injure the tissues by precipitating globulins. A temperature of 80° C. coagulates albumen and separates the skin into two layers, a blister externally and leathery beneath. Bone retains its consistence, and the other tissues form a soft coagulum removable with a sharp spoon. The final effect is complete carbonization.

The *secondary physiologic effects of diathermy* result from increased cellular activity from warmth reaching the intimate structure of different organs. Diathermy through the heart, with the active electrode over the sternum, in therapeutic doses in healthy animals, increases the pulse-rate and raises the blood-pressure temporarily without any effect on the respiration. Transversely through the chest there is a similar effect upon respiration, but none upon the circulation. A condenser application, as from a glass vacuum electrode, raises the general blood-pressure by stimulating the surface vasoconstrictors. Diathermy through the body, as by the four-cell bath, lowers the blood-pressure by relaxation of the splanchnic vasomotors, and the same is true to some extent with autoconduction and autocondensation.

The local effect of diathermy by contact application is evidenced by an experiment of Nagelschmidt. An incision in which hemorrhage has been stopped by pressure begins to bleed freely if diathermy is applied from electrodes at either side of, but at a distance from, the incision. After an ordinary treatment the place of application remains hyperemic considerably longer than if the electrode had been pressed upon the skin without any current, and for quite a while afterward the skin is hypersensitive and in a dermographic condition. Another of his experiments shows that diathermy of a part of a forearm in a blue condition from Bier's hyperemia will become a bright arterial red on the application of a diathermic current.

The effect of these currents upon nerves is to produce a sense of warmth, and also to stimulate those which are distributed to glandular organs and increase the secretion of the latter. The effect upon the vasomotor and cardiac and respiratory nerves has already been referred to, and so has the lack of effect upon motor nerves by the currents and the very great effect by the spark. The indirect high-frequency spark, applied to a metal electrode already in contact with the skin, is exceedingly active in exciting muscular contraction, and is a valuable improvement upon galvanic and faradic currents for this purpose. The effect of diathermy through the brain is to produce a sensation of compression, which passes off as soon as the current is stopped. Diathermy increases the secretion of the thyroid gland.

Except for the gonococcus, which is killed by a very slight rise of temperature, diathermy cannot be depended upon as a bactericide in living tissues; in fact, it is sometimes doubtful whether or not these currents may actually increase the vitality of the germs as well as that of the tissue cells in certain diseases.

The strength of current to be applied bears a certain relation to the size of the electrode, to the diameter of the limb when the current must traverse its length, and to the nature of the internal organs traversed.

Strength of Diathermic Current and Size of Electrodes for Bipolar Application

(After Nagelschmidt)

Electrodes.	*Milliamperes.*
Hand to hand	350 to 500
Foot to foot	500 to 700
2 cm. ($\frac{8}{10}$ inch) diameter	150 to 200
4 cm. ($1\frac{2}{10}$ inch) diameter	300 to 400
9 cm. ($3\frac{6}{10}$ inch) diameter	900 to 1000
10 by 12 cm. (4 by 8 inches)	about 2000

If the skin becomes too hot before the treatment is finished the current may be turned off and the electrodes dipped in cold water. The patient's sensations should not be taken as the sole guide, because sometimes a degree of tolerance is established to currents strong enough to blister the skin.

The duration of the application usually varies from three or four to ten or fifteen minutes.

The *application requires expert attention* every moment of the time, and should not be entrusted to a nurse or an untrained physician. There is the danger of overheating the surface tissues, and faintness or collapse from the passage of too strong a current through the heart or the brain.

Diathermy in Circulatory Diseases.—The conditions in which the treatment is chiefly useful are classified by Nagelschmidt as high arterial tension, relaxation of peripheral vessels, cardiac hypertrophy, cardiac dilatation.

Anomalies of Rhythm and Frequency.—A large electrode is applied between the shoulder-blades and another over the front of the chest. This stimulates the heart-muscle and relaxes spasm in the coronary arteries, and is useful in cases of myocardial degeneration, some valvular lesions, and angina pectoris. Aneurysm of the aorta shows subjective improvement, and a case of coronary disease which resists treatment by diathermy is regarded by Nagelschmidt as indicative of beginning aortic aneurysm. Arteriosclerosis of the brain is treated by a bipolar application or by a small solenoid surrounding the head. Local asphyxia, intermittent claudication, and Raynaud's disease are all treated by a bipolar application.

Effluves and condenser applications are indicated in low arterial tension from relaxation of the peripheral arteries, and I have obtained remarkable results in cases of phlebitis.

Diathermy in Respiratory Diseases.—The bipolar application, through the chest from side to side, is excellent in acute and chronic bronchitis and pleurisy, and applied at the upper and lower extremities of the sternum it is a specific in asthma. It often has a beneficial effect in pulmonary tuberculosis, but sometimes causes an exacerbation and had probably better be combined with the *x*-ray in this disease.

Diathermy in Other Internal Diseases.—Applied to the kidney in a number of different diseases it increases not only the water but also the solids of the urine, pathologic or normal, and eventually leads to a healthy activity and seems to be indicated in chronic Bright's disease, where it seems likely to afford a means of more permanent relief than the operation of decapsulation. It is especially indicated in cases of high arterial tension when the primary cause lies in the kidneys. It is of the same doubtful value in bacterial diseases of the kidney as of the lung. Diathermy has an excellent effect in colitis, intestinal adhesions, and chronic appendicitis, but will aggravate the latter disease if suppuration is present. This may be excluded by a count of the white blood-cells. Biliary and renal colic are benefited, except, of course, cases requiring operation. Achylia gastrica is benefited, but the opposite condition of hyperacidity is rather a contra-indication, because of the possibility of a latent ulcer which would be aggravated by diathermy. Nervous gastralgia, dyspepsia, and disturbances of motility are benefited. Nagelschmidt distinguishes the cases of exophthalmic goiter due to hyposecretion, and which should be treated by diathermy, from those due to increased secretion and which should be treated by the *x*-ray. A single test administration of iodid aggravates a case calling for diathermy.

Diathermy in Gynecology.—The best results are from a large indifferent external electrode and an active vaginal electrode. Suppurative processes are a contra-indication, but outside of them the current is of the greatest value in adhesions, uterine displacements, old exudates, and ovarian neuralgia. A strong application to the entire mucous membrane of the uterus is advised in acute or chronic gonorrheal endometritis. Sterility from infantilism is an indication for this treatment.

Genito-urinary Diseases in the Male.—Gonorrhea is curable, but the application is by no means a simple one. A special electrode, with a temperature indicator, must be used which will reach each portion of the urethral mucous membrane in turn and raise the temperature of the tissues to 43½° or 46° C. Santos has succeeded in producing a complete cure in a single application, lasting ninety minutes. Chronic gonorrheal areas and indurations and strictures are all curable by the same current applied in the urethra. Incontinence of urine as a symptom of sexual neurasthenia is treated by diathermy intra-urethrally if possible, and, otherwise, with one electrode in the rectum and the other on the perineum. Impotence of a psychic type yields to bipolar diathermy of the penis, scrotum, and perineum, and, if due to hypo-esthesia of the glans, the condenser application of a glass vacuum electrode rubbed over the surface is exceedingly effective. I have had a number of cases in which the application of a strong, hot current, but with a good contact, so as to avoid a spark effect from the glass vacuum electrode, has produced the most vigorous erections during the application and the most gratifying results after a course of treatments. Other cases have responded to the first applications, and have shown a diminishing effect from the subsequent ones and the impotence has remained; a guarded prognosis should, therefore, be given. Acute prostatis should not be treated by diathermy, but chronic prostatitis and prostatic hypertrophy are benefited by it. Nagelschmidt advises energetic bipolar diathermy in every case of acute epididymitis and funiculitis, in which he says it is extraordinarily successful if applied long enough and strong enough, and has the greatest tendency to prevent occlusion of the seminal ducts. Too weak or too short applications only aggravate the condition.

Diathermy in Joint Diseases.—The bipolar contact method is used and a sense of warmth should be felt in the joint itself. I have seen gouty deposits disappear from the finger-joints under this treatment, and it is effective also in many other forms of acute and chronic arthritis and in tenosynovitis.

Among **diseases of the nervous system** sciatica is treated successfully by energetic diathermy of each separate part of the nerve, but, of course, the effect will be only palliative if the pain is secondary to disease of some internal organ which remains undiscovered and untreated. Supra-orbital neuralgia and many others are cured. The result in herpes zoster is more uncertain. *Trigeminal neuralgia* sometimes yields to heavy diathermic currents applied externally, and in some of the cases in which this has failed Nagelschmidt has made an exceedingly valuable observation. He finds that in these cases the attacks of pain are excited by any contact or change of temperature or movement of the mucous membrane of the mouth, and that this hyperesthesia can be cured by the application of a vacuum electrode to every part of the mucous membrane. Very weak currents have to be used at first, as the application itself may bring on an attack of pain; then stronger and stronger currents. During a ten or fifteen minute application the current must be turned off several times and the glass electrode cooled. *Chorea minor* in children may be cured by diathermy.

An important application of diathermy is in the treatment of *locomotor ataxia.* Improvement takes place in a great majority of cases, chiefly in the lightning pains, the hyperalgia, and the incontinence. The patient's general condition is also better. My experience has not led, however, to the belief that a cure for the disease has been discovered. General treatment by the vacuum electrode is important. The effluve is suitable for the lancinating pains and the vacuum electrode for the girdle sensation. The latter application is to be very weak at first, but gradually increased on different occasions. Some cases which are not benefited by weak are by very strong applications. Small, very painful areas are treated by the bipolar contact application, which may at first employ electrodes at opposite sides of the painful area in cases where direct contact would excite pain. Gastric crises yield to the effluve. Vesical crises are treated with a metal catheter in the bladder full of water and an indifferent electrode held in the patient's hand and a diathermic current of 50 to 100 ma. By a course of treatment of this kind the muscular tone of the bladder and of the sphincter may be restored, although sensation and the normal impulse to urinate are still lacking. The patient is directed to urinate every three hours, and is enabled to almost or quite empty the bladder. Another effective application is with a higher voltage and indirect sparks; an indifferent electrode is held in the hand or upon the lower part of the abdomen, another metallic electrode extends into the bladder, and sparks are applied to its external end. This last treatment is also applied to the rectum for lack of muscular tone. Painful arthropathies are benefited by energetic bipolar diathermy.

Diathermy as Means of Epilation.—It has the advantage of requiring only a second to destroy a hair bulb and requires a very small amount of current. One's apparatus may be such that the weakest current is too strong, as shown by action along the entire length of the needle in the skin instead of merely at the point, and coagulation and perhaps a little sparking. In this case a water resistance may be used to reduce the strength of current.

Acne of a chronic type recurring in the same spot may be treated by a somewhat stronger diathermic current applied through a needle.

Warts are treated in the same way, and the test of complete coagulation is that the wart has become entirely movable upon the underlying tissues. No anesthetic is required, and as many as thirty have been removed at one sitting.

Xanthelasma has often been permanently removed in this way by Nagelschmidt. The weakest diathermic current is used and the needle should enter a little beyond the yellow area. The patient should be informed that some edema of the eyelid will occur, but will not do any harm.

In all these cases, and also in small papillomata, fibromata, atheromata, and cysts the patient holds an indifferent electrode in his hand and the needle is inserted before the current is turned on.

For small superficial telangiectases the needle is not to puncture the blood-vessel, but just to be pressed against the surface during the second that the current flows. There should be enough space between the several points treated to prevent the confluence of the little sores caused thereby.

Surgical diathermy, in its different forms, employs very much stronger currents than the above, and is described elsewhere (page 618). An important method is a bipolar application of low tension, high-frequency currents of sufficient milliamperage to coagulate and devitalize the tissues in the neighborhood of the active electrode or electrodes. The maximum high-frequency current required is 400 volts and 2 or 3 amperes. For most purposes both electrodes are active and are thrust into the tissue to be destroyed, but for some delicate work there is one large indifferent electrode and another small active one. The effect is one of coagulation-necrosis. The heat sterilizes the eschar, which may be left to separate naturally, or may be cut away if the operation must be carried deeper into the tissues. This is better than thrusting the electrodes so deeply into the tissues that the effect cannot be observed. There is no hemorrhage. Many varieties of tumors are treated by diathermy, and it is said to be very much the best means of operating upon hypertrophied tonsils. It is suitable for some inoperable cases of cancer, and sometimes as a preparation for an operation by closing the lymphatics and lessening the danger of absorption from the cut surface. Hemorrhoids and large or small benign as well as malignant tumors may be treated in this way.

Prostatic obstruction due to small growths of various kinds has been successfully treated[1] by the direct application of high-frequency currents by a wire passed through a cystoscope. The wire is insulated, except for an extremity of ¼ inch, which is pressed against the tissue to be destroyed or cut through.

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[1] Henry G. Bugbee, New York State Journal of Medicine, vol. xiii, No. 8, August, 1913, p. 410.

Technic of Diathermy for Hemorrhoids.—This is suitable for large, bleeding internal ones. Move bowels. Allow hemorrhoids to protrude. Cocainize. A large dispersive electrode is under the patient's side. A small active electrode is applied, and the hemorrhoid is held with forceps if there is a tendency to recede. Turn on current slowly until patient says it is hot; turn off instantly. Current about 500 ma. Apply several times to different aspects. (Humphris, "Electrotherapeutics.")

Electrocoagulation, employed by Doyen and others as a preliminary to excision of uterine and other cancers, may have one small, active, possibly puncturing electrode, and a large indifferent electrode or two small active electrodes. In either case the thermopenetration current is used, and the tissues are fairly cooked before they are cut with the knife. Dissemination through the lymph-channels and blood-vessels is prevented.

Undamped Oscillations, Duddell's Singing Arc, and the DeForest Needle.—High-frequency currents with damped oscillations are analogous to the quickly suppressed oscillations of a tuning-fork in water, while the long-continued series of oscillations of uniform extent, when only the obstruction of the air is encountered, gives a better idea of undamped oscillations. One use of these oscillations is in connection with the *DeForest needle* or *cold cautery*. This is like a small platinum blade, which has a handle insulated by glass or hard rubber. The direct electric-light current passes through an arc lamp in which the electrodes are broad and close together; the electrodes of the lamp are connected with a self-inductance and a condenser. Viewed in a revolving mirror, the arc light may be seen to fluctuate with the alternate charge and discharge of the condenser; these oscillations are superimposed upon the direct current forming the arc, and the alternate greater and less heating of the air may produce a musical note (Duddell's singing arc). The undamped oscillatory current free from the direct current may be taken, usually as a monopolar discharge, from either end of the self-inductance. A heavily insulated wire carries this current to the DeForest needle. The current has oscillations of the usual high frequency, but of very low voltage, usually not more than 100. No long sparks, therefore, can pass from the needle to the patient. The needle itself remains cool, while the current encounters much greater resistance in the tissues, which are therefore cauterized. In one method it does not touch the surface, but is drawn along a straight line near the surface, the sharp, hot, almost noiseless spark cuts the flesh like a knife and leaves a clean red surface, not

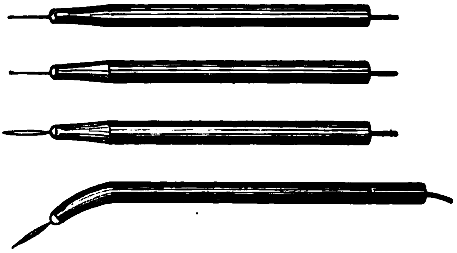
Fig. 384.—DeForest needles.

charred or blackened, but without any capillary hemorrhage. The cut surface is sterile. This makes an ideal method for many sorts of surgical cutting, incising abscesses, and especially excision of tumors, where it has the great advantage over the knife that it seals the capillaries and lymphatics against infection from the tumor elements. It is not suited, however, to such work as freeing a nerve or a tendon from adhesions. It would not be a desirable means of operation upon an artery.

The other application of the DeForest needle, by which it is plunged into the tissues, produces a regular coagulation-necrosis of greater or less extent, depending upon the depth to which the needle penetrates and the length of time for which the current is applied. It is suited to the destruction and sterilization of a tumor of any size or nature. The entire outfit may be portable.

PHENOMENA ACCOMPANYING THE TRANSMISSION OF ELECTRICITY THROUGH GASES

It is only static or other very high-tension electricity which can be transmitted through gases, and the general consideration of the subject may be entered upon at this place. Under ordinary conditions the air or any other gas in contact with a charged body does not become charged and is not a conductor of electricity. If it did so, of course, the body would soon lose its charge by a process of convection; each portion of the air as it became charged being repelled and giving place to another portion, which would in turn take away a certain portion of the charge. Since gases do not ordinarily become charged in this way, it is interesting to note some of the ways in which it can be accomplished and in which they can be rendered conductors of electricity.

Gases in contact with the surface of liquids in which splashing or even quiet waves occur become electrified. One of the practicable forms of static machine is dependent upon the charge acquired by a jet of steam. These are some of the ways in which a gas may be ionized, a condition which will be explained later.

Other means of ionizing gases and rendering them capable of receiving and transmitting electricity are of greater interest in electrotherapy, among them are especially exposure to the *x*-ray, the ultraviolet ray, and some of the rays from radio-active substances, also by the passage of a spark from an induction-coil. This is the way in which the current is started through the mercury vapor in some forms of the Cooper Hewitt and similar lamps.

IONIZATION OF GASES

By some one of the above processes, or of several others which might be mentioned, some of the molecules of the gas are dissociated into positively and negatively charged ions. An excess of positive ions in a gas will, of course, cause the gas to have a charge of positive electricity. An example of the way in which this may come about is seen when a gas becomes electrified by contact with an incandescent metal or by the passage of an electric arc through it. In consequence of the high temperature some of the molecules of the gas become dissociated into positive and negative ions. Some of these combine with the incandescent metal or with the terminals of the arc. In the resulting compound the metal is the electropositive element and will take negative ions from the gas and leave the latter with an excess of positive ions.

The Atom According to Sir J. J. Thomson.—It is composed of electrons or negative particles grouped in approximately co-planar and concentric circles and in active revolution, the system being within a sphere of positive electricity. The number of electrons in an atom is calculated to be eight times its atomic weight.[1]

Ions are atoms charged by electrons which are supposed to be

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[1] H. A. Wilson, Phil. Mag., xxi, p. 718, 1911.

$\frac{1}{1000}$ about the size of a hydrogen atom. A positive ion is a group of particles surrounding a positive charge; a negative ion is a group of particles around an electron. In a vacuum tube such as an *x*-ray tube electrons travel at an average rate of 20,000 miles a second, and under certain other conditions they may travel as fast as 50,000 miles a second. No matter how complex the chemic formula of a gas may be, each ion is usually a particle of one or other of the single elements which make up the gas.

The *ionization* of a gas by the ultraviolet ray takes place only when the light is reflected from a fluorescent substance or from the surface of a metal immersed in the gas, and the gas is only able to discharge a charged body in its neighborhood which is not illuminated by ultraviolet rays when the charge on the body is positive. The *x*-ray, on the other hand, makes the gas through which it passes a conductor of electricity, independently of any reflection of the rays, and the gas thus made to assume a conducting state is able to discharge negatively as well as positively charged bodies when it comes in contact with them. Air ionized by the *x*-ray retains this property if blown through a bellows or if heated, but it loses its condition of ionization if it is made to bubble through a liquid or to pass through a plug of mineral wool, or if a current of electricity is passed through it. A gas ionized by the *x*-ray rapidly loses that property by contact with either non-conductors (insulators) or conductors.

Electropositive metals lose negative charges to the air when exposed to ordinary light and do not require the presence of ultraviolet rays.

A gas which has been ionized and rendered a conductor of electricity will transmit electricity at a certain maximum rate which is not exceeded, no matter how much the potential or voltage may be increased. The most satisfactory hypothesis is that each ion of gas can carry only a certain charge of electricity, and with a definite number of ions liberated in the gas only a certain rate of transmission of the current is possible. An ion which has performed its function of carrying an electric charge apparently becomes neutralized or bound again and is no longer capable of carrying electricity. Hence, a layer of ionized gas ceases after a time to transmit the current, and a thin layer ceases sooner than a thick layer. The maximum rate at which a gas will transmit electricity is different in various gases and is called their saturation current. That of mercury vapor is about twenty times the saturation current of air. It is interesting to note that the absorption of the *x*-ray by different gases is in proportion to their saturation currents.

There are two different ways in which the extent to which air has been ionized is used in practical therapeutic measurements. One method is by observing the time which an electroscope requires to become discharged after having received a standard charge and being exposed to ionized air. This method has been used in the measurement of the amount of *x*-ray applied in therapeutics, the electroscope being placed at a certain distance from the *x*-ray tube and exposed to the direct rays from it at the same time that the patient is being treated. The rapidity with which the electroscope becomes discharged certainly does indicate the degree of ionization of the surrounding air, but whether this is due exclusively to the influence of the *x*-ray or even bears such a practical relation to it as to form a reliable means of *x*-ray dosage is a serious question. Another method of measuring the electric conductivity of ionized air is by having a thin layer of air between metal plates which are kept at a constant difference of potential by a galvanic battery, and ionizing the air by exposure to radium or other rays. The ionization of the air allows a current to pass across the air space and complete the circuit. The strength of this current as shown by a galvanometer indicates the degree of ionization of the air. This method is in constant use for measuring the radio-activity of uranium, polonium, thorium, and radium.

The *conductivity* of ionized air is influenced by pressure, but varies either as the pressure or as the square root of the pressure.

Hertz discovered in 1887 that when ultraviolet light falls upon a spark gap the discharge is facilitated. This was the basis of photo-electric signalling. The artificial light richest in the ultraviolet ray was found to be an arc light of which one pole was zinc or cadmium.

Cathode, Lenard, and *x*-rays all render any gas through which they pass a conductor of electricity.

An ionized gas is an electrolyte, *i. e.*, a substance through which electricity may pass and in which the current is formed by the motion of positively charged ions in one direction, and negatively charged ions in the other direction. In the case of a liquid, which is really the most characteristic electrolyte, the accumulation of electropositive ions at one pole and of electronegative ions at the other pole is so great that there is a demonstrable change in molecular composition. The liberation of hydrogen gas at one pole and of oxygen gas at the other when electricity is passed through water is an example of this; the water being an electrolyte, and the chemic change being called electrolysis. The motion of the ions toward one pole or the other may be called phoresis. Cataphoresis, or the motion of electropositive ions through an electrolyte toward the negative pole, has important uses in electrotherapeutics.

This same process of electrolysis takes place in solids and gases, though the molecular change or the change demonstrable by chemic analysis is of far less importance than is the transmission of electricity and its secondary effects, radiant and otherwise, produced by the transmission of the current.

If a platinum wire is heated red hot in hydrogen gas, the platinum becomes positively, and the hydrogen negatively, charged. The same is true of iron or palladium wires. Air and all other gases differ from hydrogen in being positively charged, except mercury vapor, which is not charged at all.

If an electric arc is passed through oxygen gas the oxygen becomes positively charged and will discharge a negatively charged body, or will give a positive charge to an uncharged body. The reverse effect is produced when an electric arc is passed through hydrogen.

Positive and Negative Ions at the Same Discharging Point.—J. Zeleng[1] finds that ions of both signs can be detected near a point from which a static current of unvarying polarity passes through the air to a plate. With a discharge of 7 micro-amperes and the point positive, the number of positive ions is 250 times more than the negative ions

Gases which arise from flames are electrified and are conductors of electricity. Both positive and negative ions are to be found in a flame; these make a flame an excellent conductor of electricity.

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[1] Phys. Rev., xxxiii, 1911, 70.

The conduction of electricity through gases is not governed by Ohm's law that the current is equal to the electromotive force divided by the resistance. It is not true, for instance, that multiplying the electromotive force or the voltage increases the current flow in the same proportion.

Steam arising from electrified water is not electrified. Vapor arising from boiling mercury is not electrified, no matter how strongly the liquid mercury may be charged.

When a jet of hydrogen is burned in the air the unburned hydrogen in the jet is negatively charged. Lavoissier and Laplace as long ago as 1782 noted the fact that hydrogen rapidly liberated by the action of sulphuric acid upon iron possesses a strong positive charge.

According to J. J. Thompson's observation, the presence of an electric charge upon a drop of water tends to prevent the evaporation of the water. Crookes, on the other hand, has found that evaporation takes place more rapidly from the surface of water which is negatively electrified than when the water is not electrified. Mascaret's observation is that either positively or negatively charged water evaporates faster than water which is uncharged. The possibility of error in these observations lies in the lack of uniform conditions as to the humidity and the temperature of the surrounding air and as to mechanic currents in it and in the lack of uniformity in the conditions which would ionize the air and influence its electric conductivity. If the air in contact with the surface of the water were ionized it would receive a charge of electricity from the water and be repelled from it, giving place to a fresh portion of air, which in its turn would be charged and repelled. Each portion of air would, of course, absorb more or less water and the result would be a more rapid evaporation than the normal, just as if a current were produced in the air in any other way. There are many ways in which the air might become accidentally ionized to a sufficient extent to affect the result in an experiment of this kind.

THE PASSAGE OF ELECTRICITY THROUGH A VACUUM

If the air or any other gas in a glass tube be partially exhausted by means of an air-pump, and there are two wires leading into it, the phenomena observed on connecting it with the source of high potential electricity may vary with the degree of exhaustion.

Before the tube has been exhausted a discharge will take place through it as a zigzag spark passing through it from one wire to the other, and the same is true of a tube in which the gas has been exhausted, but into which air has entered in consequence of a leak or a puncture. Such a state of things sometimes occurs with an *x*-ray tube, and it indicates the presence of so large a leak that no amount of regulation of the vacuum will be effective until the opening has been found and sealed up. The discharge through a tube in this condition does not differ materially from that which takes place through the open air, and as in the latter case the distance across which the discharge will pass is strictly limited to the number of inches which corresponds to the voltage or the difference of potential of the two poles. The spark length which certain voltages will produce is variously estimated and depends partly upon the shape and material of the discharging surfaces. A spark 1 inch long through the open air, or in a tube filled with air, requires at the least a potential of 10,000 volts.

A vacuum tube exhausted to the Geissler degree of $\frac{1}{1000}$ atmosphere does not become luminous on the passage of a continuous current, no matter of what tension. The moment the current is made intermittent or alternating the tube lights up. The illumination also takes place if the tube contains mercury vapor or certain other gases.

A tube exhausted to this slight degree becomes filled with reddish, bluish, or violet light when the high-tension interrupted current is turned on, there being no visible or audible spark passing through it, and this light is more or less stratified, seeming to pass through the tube in waves. Geissler tubes (Fig. 385) of different shapes were favorite laboratory toys and were the forerunners of the Crookes tube and of a modern focus *x*-ray tube. A tube which becomes filled with bluish or reddish light allows the cathode stream to pass directly from the cathode to the anode and does not present as great resistance to the passage of electricity as one with a higher degree of vacuum, *i, e.*, from which the gas has been more completely removed, and it does not generate a useful quantity of *x*-rays. The study of all the phenomena caused by the cathode rays has been more successfully performed upon the tubes with a higher vacuum.

A **Crookes' tube** is a glass tube containing an almost complete vacuum of about $\frac{1}{1,000,000}$ atmosphere.

Crookes' theory in regard to a tube exhausted to this degree was that the molecules were so few and far between that they could move from one wall of the tube to the other without encountering other molecules. This is the ultragaseous state of matter. It was formerly believed that the cathode ray consisted of molecules of the residual gas, but it is now thought to consist of particles of matter, perhaps only one-thousandth the size of an atom torn from the atoms and thrown from the surface of the cathode.

Such a tube offers great resistance to the passage of electricity, and even with a source of very high potential will transmit a current of only a few milliamperes. If its two terminals are simple wires leading into the tube not much change may be noted on turning on the current. There may be a little fluorescence of the glass around the negative pole and this may be of the greenish-yellow tint which is excited in ordinary glass by the cathode ray. This is apt to be greatest around the cathode or negative wire. The rest of the tube may present little or no color, there will be some heating of the glass near the two wires, and this is often greatest near the cathode. While a simple Crookes' tube of this construction does not look very unusual, the phenomena taking place in it are of great interest and their study led to the discovery of the *x*-ray.

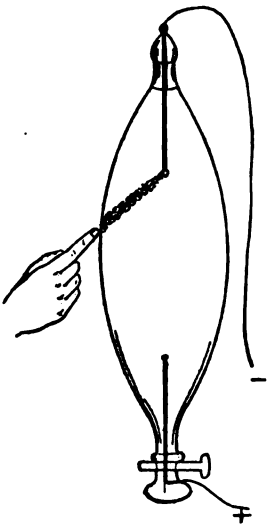

Fig. 385.—Geissler tube. Cathode stream attracted by finger.

The Cathode Ray.—The most important phenomena produced by the passage of electricity through a Crookes tube are results of the cathode ray. This is probably a stream of material particles much smaller than atoms driven from the cathode at a right angle to its surface and carrying a negative charge of electricity. The other hypothesis that the cathode ray consists of vibrations in the luminiferous ether does not explain many of the phenomena as well as this corpuscular theory.

According to the theory adopted in the present work the cathode stream of material particles proceeds from every part of the cathode at a right angle to its surface, and without regard to the position of the anode. The cathode stream is invisible, but its presence can be readily demonstrated to the eye by the fluorescence which it will excite in various gaseous, liquid, or solid substances placed inside the tube and by the mechanic motion which it will produce. Sometimes in an *x*-ray tube if the vacuum becomes very low the visible fluorescence produced by the passage of the cathode ray through the gas can be seen as a bluish streak passing from the cathode to the anticathode. If the cathode consists of a straight rod or wire pointing toward the anode, the cathode stream will proceed chiefly from the lateral surface of the rod, since that is of greater extent than its end. It will cause motion in a little wheel made up of several vanes or fan-like disks revolving on an axle in the same way that a current of air or water produces motion in a wind-mill or a water-mill. The best arrangement is to have one surface of each vane covered with polished metal foil and the other surface roughened, or a shield may be placed so that the cathode stream can strike only the vanes on one side of the wheel. The unopposed impact causes the wheel to rotate. The same motor effect can be produced in a tube in which the cathode is formed by a disk or a concave circle of metal, as is the case in an *x*-ray tube. This directs the cathode stream toward the particular spot desired to influence.

The luminous effects of the cathode ray are seen in the fluorescence it excites in the glass wall of the tube, and this is of different colors with glass of different composition; for instance, glass containing a large percentage of lead changes to a beautiful blue, while the ordinary glass assumes a yellowish-green tint. If a solid object such as a glass or metal disk or cross is placed in the path of the cathode stream, a distinct shadow is cast upon the wall of the tube. Beautiful effects are seen when various substances are introduced into such a tube. Under the influence of the cathode ray the following substances show phosphorescence with the specified colors:

Phosphorescent Colors Produced by the Cathode Ray (*J. J. Thomson*).

$CuSO_4$	Faint orange.
$CuSO_4 + MnSO_4$	Bright green.
$SrSO_4$	None.
$SrSO_4 + MnSO_4$	Bright red.
$BaSO_4$	Faint dark violet.
$BaSO_4 + MnSO_4$	Dark blue.
$MgSO_4$	Red.
$MgSO_4$ + 1 per cent. $MnSO_4$	Intense dark red.
$ZnSO_4$	Bluish.
Na_2SO_4 + 0.5 per cent. $MnSO_4$	Intense brownish yellow.
$CdSO_4$	Yellow.
$CaFl_2$	Faint blue.
$CaFl_2 + MnH_2$	Intense blue.

The most striking effects are produced upon what Thomson calls solid solutions. A great deal of our knowledge of the transmission of electricity is due to the published works of Professor J. J. Thomson of Cambridge University, England (The Discharge of Electricity through Gases). These "solid solutions" are formed when two salts, one greatly in excess of the other, are precipitated simultaneously from a liquid in which both are held in solution, the familiar barium platinocyanid of the fluoroscopic screen for *x*-ray work is an example of a "solid solution."

The cathode stream travels at the rate of about 20,000 miles a second and in a straight line, from which, however, it may be deflected in a variety of ways. It is arrested by the glass wall of the tube, and a thin sheet of glass placed within the tube and across the path of the cathode stream casts a very dark shadow contrasting with the fluorescence of the wall of the tube. Gold-leaf is less opaque. A sheet of aluminum 0.00265 millimeters thick forming a window in the wall of the tube will allow the cathode ray to pass through it in sufficient amount to produce visible light and to cause phosphorescence in bodies outside of the tube. Experiments with a great variety of substances have shown that the most phosphorescent substance is a piece of tissue paper soaked in a solution of pentadekylparatoleketon.

The cathode rays suffer diffuse reflection when they fall upon a surface, whether it be of an insulator or of a conductor. Cathode rays start in all directions from such a surface, especially if the rays have struck it obliquely. And the substance struck generally becomes itself a cathode and emits cathode rays, principally normal or perpendicular to its surface. These reflected or secondary cathode rays occur independently of the existence of *x*-rays, the latter are ethereal vibrations, while the cathode rays consist of particles of matter. The cathode stream undergoes no regular refraction, but it may be deflected from its straight path by a magnet.

Deflection of the Cathode Stream by a Magnet.—The cathode stream is deflected toward a magnet (Fig. 386) and this is the case with the positive or negative pole or both poles, as in the case of a horseshoe magnet.

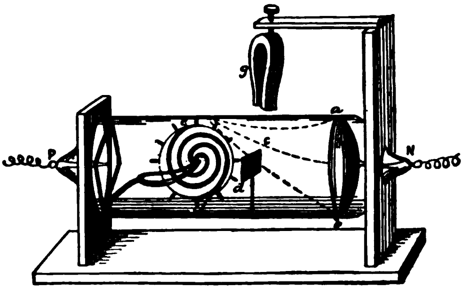

Fig. 386.—Cathode stream deflected by a magnet.

Birkeland[1] discovered a magnetic spectrum in the cathode stream, some particles being more deflected than others, and the result being a broad band of phosphorescence instead of a single spot.

Strutt[2] showed that this was due to inequalities in voltage in successive discharges from an induction-coil, and that it does not occur with the discharge from a large static machine or from a large battery of storage-cells.

Deflection by Another Cathode.—In a tube with two cathodes so arranged that the cathode streams are parallel when they leave the surface of the cathodes, the two streams will be found to repel each other and to form somewhat divergent curves. This seems almost

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[1] Comptes Rendus de la Société Française des Sciences, cxxiii, p. 92, 1897.

[2] Phila. Mag., vol. v, No. 48, p. 478, 1899.

conclusive evidence that the cathode stream consists of particles of matter charged with negative electricity. The particles in both streams are similarly charged and consequently repel each other. This property is taken into account in the construction of an x-ray tube, the platinum disk or anticathode upon which the cathode stream is to be focused is not placed at the center of curvature of the cathode mirror, but at a point considerably further away, the repulsion between the particles of the cathode stream deflects them so that they meet at a point beyond what would be the focus if each particle proceeded in a straight line at a right angle to the part of the surface of the cathode from which it started.

Lenard Rays.—The cathode rays which have passed through an aluminum window and so have escaped from the vacuum tube present very similar characteristics to the cathode rays inside the tube, but are given the distinguishing name of Lenard rays, after their discoverer. They spread out very diffusely and cast shadows of solid objects which are larger than the geometric ones or larger than would result from rays traveling in a perfectly straight line from a single point. They cause photographic effects, but since the x-ray is also present under these conditions it is hard to say just what part the Lenard rays play in this. These rays are arrested by quartz crystal, but pass through alum. They discharge bodies charged with either positive or negative electricity as do the x-rays. These rays and all the properties attributed to them were discovered before the x-ray, and some of these properties may be due to the latter; still, the discovery of the x-ray has not thrown any doubt upon the existence of Lenard rays. There is, however, some doubt as to whether the Lenard rays consist of material particles or of vibrations in the luminiferous ether. Their passage through solid bodies gives some ground for the latter theory, but J. J. Thomson believes that they are corpuscular in nature. The cathode rays lose about 10 per cent. in velocity in passing through an aluminum window and emerging from a Crookes tube as Lenard rays.

Channel Rays (Kanalstrahlen).—Goldstein[1] discovered the presence of these rays in a vacuum tube. They are produced with a perforated cathode, are found only near the cathode and behind it, and are not deflected by a magnet, and their only known property is that of being accompanied by luminosity. Possibly they are jets of phosphorescent gas emitted from the perforations in the cathode by a sort of explosion. They are made up of positively charged particles of matter.

Lodge's Theory of the Transmission of Electricity Through Gases.[2]—Lodge considers that the principal part is played by positive ions passing from the anode to the cathode along the path of least resistance. The rôle of the negative electrons projected from the cathode normally to its surface he regards as subsidiary, not contributing directly to the transportation of electricity. The electrons, however, are emitted with great force and velocity and, according to Lodge's theory, they may collide with the positive ions and so interfere with their access to the cathode, and under certain circumstances prevent the flow of the current. For instance, in a valve tube the size and position of the electrodes is such that with an alternating potential only currents in one instance can easily get through. The current can easily pass in such a direction that

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[1] Berliner Sitzungsberichte, 39, p. 691, 1886.

[2] Sir Oliver Lodge, Phil. Mag., 22, 1911.

the large electrode, with free access to its surface, is the cathode, and is greatly impeded when the small electrode in a narrow part of the tube is the cathode.

Magnetic Rays or Magnetocathodic Rays.—Righi[1] distinguishes these from ordinary cathode rays by the fact that in the former some of the electrons unite with positive ions, forming systems analogous to a planet and its satellite the rotation of which is controlled by the magnetizing current. These rays result from the action of a magnetic field upon a cathode stream. They are repelled to a portion of the tube where the magnetic field is weakest; there they become dissociated and an accumulation of positive ions is demonstrable.

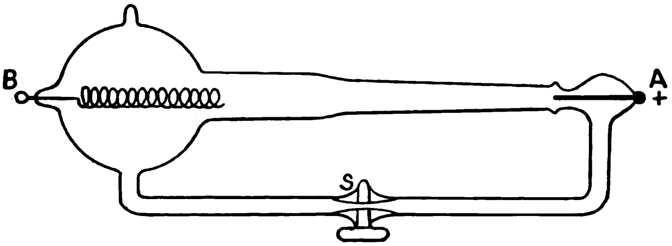

Fig. 387.—Lodge's valve tube.[2] This acts as an efficient rectifier when the stop-cock S is open, affording an unobstructed path for the positive ions from the anode A to the cathode B, avoiding collision with the cathode particles.

The *x*-Ray.—When the cathode ray as a stream of material particles traveling at the rate of 20,000 miles a second strikes any solid object, such as the glass wall of the original Crookes tube or the platinum disk in the modern *focus* *x*-ray tube, the impact gives rise to the ethereal vibrations known as the *x*-ray. Were particles as large as pebbles to bombard any hard surface at a tremendous velocity the effect would be vibrations in the air which would be perceptible as a deafening noise. In a vacuum tube the moving bodies are only one-thousandth the size of an atom and the speed at which they strike is inconceivably great. The result is equally beyond the range of the human senses; vibrations in the luminiferous ether five or ten times as rapid as the most rapid vibrations of visible light, and millions of times as rapid as the highest pitched audible sound-waves. A special part of the present work is devoted to the consideration of the *x*-ray. It is mentioned here only as one of the phenomena produced by the passage of electricity through a vacuum tube and for the purpose of detailing the differences between the *x*-ray and the cathode ray.

Differences Between the Cathode and x-Rays.—The cathode rays differ chiefly in the facts that they carry a charge of negative electricity and that they are deflected from their straight path by the influence of another cathode or of a magnet. Cathode rays consist of particles of matter, while the *x*-ray is a form of motion like light and heat. The cathode ray is essentially a phenomenon occurring inside a Crookes tube and has very little penetrating power, while the *x*-ray is chiefly known by its effects outside of the tube and has great penetrative power.

Similarities Between Cathode and x-Rays.—They both ionize the air,

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[1] Le Radium, 9, August, 1912, 300.

[2] Ibid., 1912, p. 55.

rendering it a conductor of electricity, act on photographic plates, produce fluorescence, and are incapable of regular reflection, refraction, or polarization. They both give rise to cathode rays and x-rays when they strike a solid substance.

Passage of Electricity Through a Practically Perfect Vacuum.—Experiments by Coolidge with x-ray tubes, exhausted far beyond the ordinary limit of $\frac{1}{1,000,000}$ atmosphere, show that no current passes under any voltage while the electrodes are cold, but that it will do so if the cathode consists of tungsten wire and is heated by a current passing through it. In that case even as low a voltage as 220 may send a current through this vacuum. A Röntgen ray tube constructed upon this principle is described on page 745.

Special Forms of Geissler Tubes.—Vacuum tubes which are not exhausted to the x-ray degree have already been spoken of. In the original type there were two leading-in wires and the whole bulb became filled with colored light which was more or less stratified. This light could be concentrated at one spot if the finger was applied to the side of the bulb (Fig. 389) and the finger then received a slight discharge of electricity from the surface of the glass. From this early type have been evolved the vacuum electrodes which form such an important part of high-frequency apparatus. A glass bulb with a suitable stem (Fig. 390) and exhausted to the proper degree may be excited by connection with one pole of a static machine, x-ray coil, or high-frequency apparatus. This does not require the presence of any wire at all leading into the tube, and if there is none, the electrification of the enclosed gas must take place by a sort of condenser action. The metal handle is charged from the static machine, we will say, and induces in the gaseous contents a

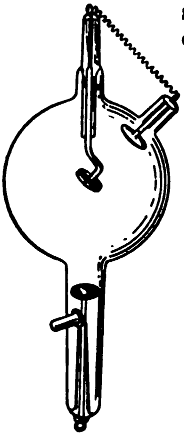

Fig. 388.—*X*-ray tube.

Fig. 389.—Geissler tube, showing cathode stream.

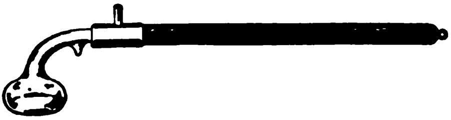

Fig. 390.—Geissler tube for use as a vacuum electrode. Insulated handle.

charge through the glass wall of the tube. The gas becomes luminous with a violet light and with a certain degree of vacuum such a tube will be found to give out light which contains an appreciable amount of the ultraviolet rays, the invisible actinic rays beyond the violet end of the solar spectrum. The presence of the ultraviolet ray is most readily demonstrated by the fluorescence it excites in a piece of Willemite held near the tube. The activity of the tube is greatly increased by making some additional connection, for instance, by touching the other end with the hand. When there is a leading-in wire passing through the glass wall of the tube the visible effect is the same, but it does not take so strong a charge of electricity to excite it. The color of such a tube varies with the degree of exhaustion, the kind of gas contained in it, and the composition of the glass. Such a tube may be made long and curved into a flat spiral (Fig. 391) with leading-in wires connected with the two poles of an x-ray coil, and gives a beautiful violet and ultraviolet radiance with very little discharge of electricity to the patient.

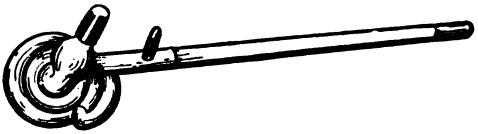

Fig. 391.—High-frequency vacuum electrode with two leading-in wires.

Vacuum Tubes for Electric Illumination.—The first electric light on record was reported by Hawksbee two hundred years ago. It was a vacuum tube which when connected with one pole of a frictional static machine gave sufficient light to read large print by.

The practicable vacuum tube lights at the present day all depend upon the fluorescence excited in the residual gas by the passage of an electric current through it. In the Cooper Hewitt lamp the current is of the direct 110 volts. In the Moore lamp an alternating current of 5000 volts is used. In the Tesla light the voltage has been raised by a high-frequency transformer.

The *Cooper Hewitt lamp* (Fig. 392) consists of a vacuum tube about 1 inch in diameter and from 2 to 4 feet long. It contains a certain quantity of metallic mercury and, of course, is filled with mercury vapor. The latter is a very poor conductor of electricity when cold, and to start the current it is necessary either to tip the tube and make a complete connection of liquid mercury from pole to pole, or else to pass a high-tension current of at least 1000 volts through it from an induction-coil. In either case the 110-volt continuous current is thereafter transmitted through the gas and causes brilliant fluorescence. The smaller size tube gives 300 and the larger size 700 candle-power. The tube does become hot, but not nearly as much of the power is consumed in this way as in the incandescent electric lamp. Only 3½ amperes of current are used. Its efficiency is correspondingly high, in fact, the claim is made that it requires only ¼ Watt per candle-power, while a 16-candle-power incandescent lamp requires ½ ampere and 110 volts, making 55 Watts; or 3½ Watts per candle-power. The cathode terminal should be liquid mercury at the lower end of the tube. The positive terminal is usually of iron. The Cooper Hewitt lamp has about the same efficiency as the electric arc lamp. The light from this lamp presents the spectrum of incandescent mercury vapor, it is rich in violet rays, and almost entirely lacking in red rays. It is not especially rich in ultraviolet rays, as tested by Willemite. A very interesting observation may be made with the spectroscope in connection with this lamp described in the next paragraph.

Nature of Fluorescence.—Fluorescent substances have the property of intense absorption of light at their surfaces and of slowing the rate of vibration of light falling upon them. In the case of the mercury vapor light a piece of cloth saturated with a solution of a fluorescent substance like rhodamin, and dried, may be wrapped around the luminous tube. Red lines and others not in the mercury spectrum will immediately be seen with the spectroscope. It is in the same way that Willemite slows up the vibrations of invisible ultraviolet light and changes it to a brilliant green. Something of an analogous nature must take place in connection with the ionization of the air by the ultraviolet ray. It will be remembered that the ultraviolet ray ionizes a gas and renders it a conductor of electricity and capable of discharging a charged body only when the light is reflected from a fluorescent substance or from a metal immersed in the gas.

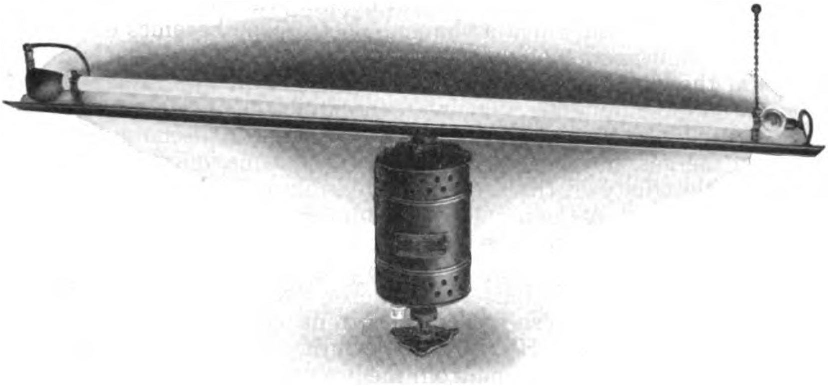

Fig. 392.—Cooper Hewitt lamp.

The Cooper Hewitt light, of course, does not give the natural color to objects illuminated by it. Red objects appear blue or purple and every little capillary in the skin and the entire mucous surface of the lips appears bluish. The visible effect is as if the person were dead and decomposition had begun. While it is not suitable for general illumination, excellent photographs may be made by it, either originals or reproductions from others. It is made up almost exclusively of the most actinic rays of visible light and on this account has seemed of value to the present author in the treatment of tuberculosis by light baths.

The uviol lamp is made of glass which transmits a greater percentage of ultraviolet rays. The eyes, however, should be protected from a light so rich in ultraviolet rays.

Moore's Vacuum-tube Light.—Tubes of any length may be used and passed from room to room, distributing the light just like the steam-or gas-pipes. They are connected at a central box in the cellar or elsewhere with the alternating current of 110 volts, or with the 110-volt direct current modified by the use of a vacuum-tube rotator, producing extra currents by its sudden breaks in passing through an electromagnetic coil. Either of these currents is passed through a step-up transformer, raising it to 5000 volts. Any kind of vapor may be used in the tubes and light of any desired color and spectrum may be produced. Daylight may be imitated very closely. The light is accompanied by very little heat.

The Nikola Tesla Vacuum-tube Light.—This is produced in a vacuum tube of any length by charging and discharging a condenser and passing the discharge through the primary of an induction-coil. The secondary current thus obtained is of very high voltage and frequency and can be used with tubes with or without leading-in wires.

Disruptive Nature of Vacuum-tube Transmission.—A discharge of electricity through a gas which has been ionized can, it is true, take place by simple conduction, as in the apparatus employed for testing the radio-activity of radium salts, or in testing the quantity of the x-ray by the rapidity with which a charged electroscope becomes discharged, but such a transmission of the current is as free from any special phenomena as if the charge were conducted by an equal length of copper wire. The discharges through the vacuum-tubes which have just been described are essentially of the nature of sparks or disruptive discharges breaking through the gas, not carried by it. Still the same ionized gas will also transmit electricity in the silent and invisible manner characteristic of true conduction. A Cooper Hewitt lamp, for experiment, may have a couple of leading-in wires at opposite sides near the middle of the length of the tube, and these two opposite wires may be connected with wires leading from a galvanic battery of one or two cells. A galvanometer placed in the circuit will show that no current passes through the battery circuit until the Cooper Hewitt light is turned on, and the rarefied gas between the two wires coming from the battery and leading into the tube is ionized and becomes a conductor of electricity.

A *chemically active form of nitrogen* is produced when pure nitrogen gas is used in a Geissler tube and an electric discharge takes place through it.

The explosive distance in vacuum tubes is increased in a magnetic field parallel with the space, and there is a best strength for the field.[1]

A tube may light up in a field of 1400 gauss and become dark in a field of 3000 gauss (electromagnet with a current of 16 amperes).

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[1] Gouy, C. R. de la Soc. de Biol., 150, 1910, 1552, and 151, 1910, 1320.

PHOTOTHERAPY

Light as a therapeutic agent has become very prominent during the past few years, and its action is due to the luminous rays, the chemic rays, and the heat rays. It was thought at one time that the heat rays were confined to the infra-red and red of the spectrum, but it is now known that there are heat rays through the entire spectrum. The chemic rays were at one time thought to be confined entirely to the blue and violet-blue portion of the spectrum, but it is now known that they also are found throughout the entire visible spectrum. The heat rays found in the infra-red part of the spectrum are invisible.

Temperature of Incandescence.

Degrees Fahrenheit.	
1000	Red rays.
1200	Orange rays.
1300	Yellow rays.
1500	Blue rays.
1700	Indigo rays.
2000	Violet rays.
2130	All colors = white light.

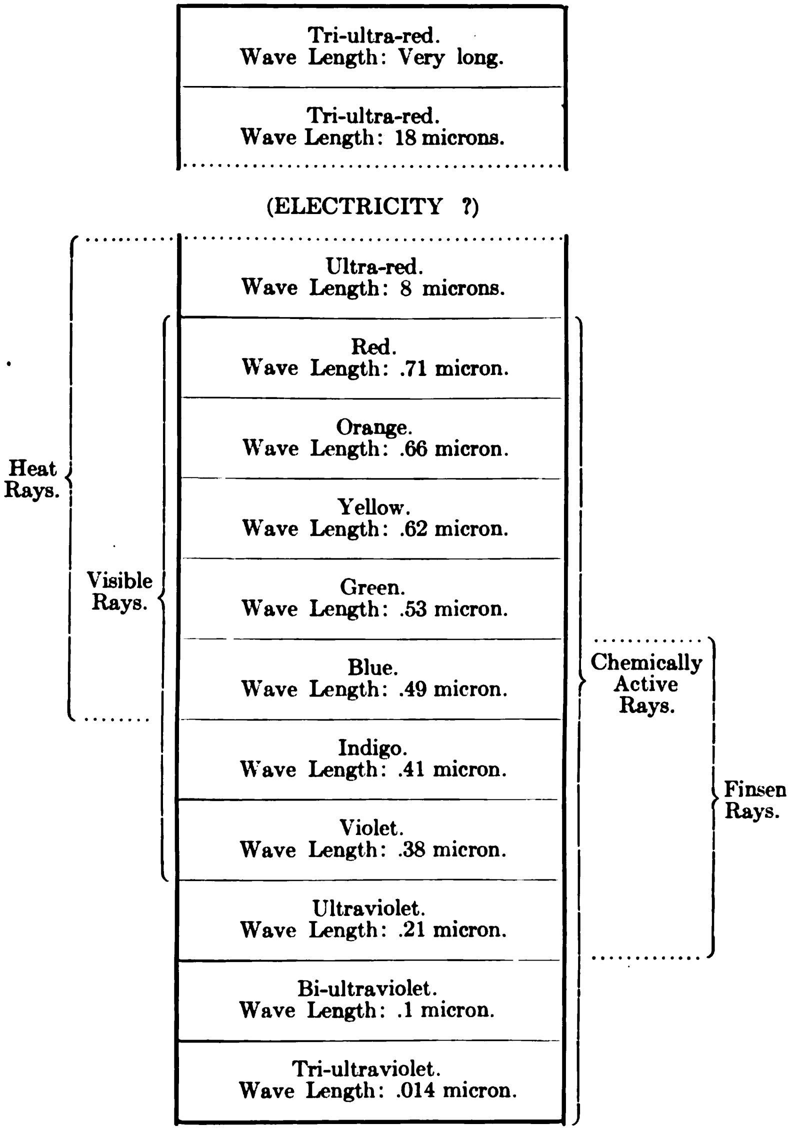
The intensity of the light increases faster than the temperature. Platinum wire at 2600° F. gives out forty times as much light as at 1900° F.

Gas gives 1 part visible	24	parts	invisible	rays.
Incandescent filament gives 1 part visible	23	“	“	“
The electric arc gives 1 part visible	9	“	“	“

The temperature of the voltaic arc is about 3000° C. for the positive carbon and 2500° C. for the negative.

In addition to the ordinary chemic rays which accompany the visible rays of light, there are what are known as the ultraviolet rays; these are beyond the violet and are also invisible. An illustration of what are known as infra-red rays is the heat effect noticed when the hand is brought near a stove in which there is a fire. These rays are more penetrating than the visible rays of the spectrum. The strength of light varies inversely as the square of the distance; this is an important law to remember; thus, if at a distance of 30 inches the candle-power is 500, then at a distance of 60 inches the candle-power will be only one-quarter, or 125 candle-power. The usual distance from the filament at which the candle-power of an incandescent lamp is measured is 30 inches, so that if the patient is at this distance from the filament, the full rated candle-power of the lamp is being used. Another point to remember is that light is most effective when it strikes the surface at right angles. In order to compare different lamps an actinometer such as is used by photographers can be placed on the patient. In order to use this correctly, all other light must be excluded.

THE COMPLETE SPECTRUM OF LIGHT



Tri-ultra-red.
Wave Length: Very long.

Tri-ultra-red.
Wave Length: 18 microns.

(ELECTRICITY ?)

Ultra-red.
Wave Length: 8 microns.

Red.
Wave Length: .71 micron.

Orange.
Wave Length: .66 micron.

Yellow.
Wave Length: .62 micron.

Green.
Wave Length: .53 micron.

Blue.
Wave Length: .49 micron.

Indigo.
Wave Length: .41 micron.

Violet.
Wave Length: .38 micron.

Ultraviolet.
Wave Length: .21 micron.

Bi-ultraviolet.
Wave Length: .1 micron.

Tri-ultraviolet.
Wave Length: .014 micron.

—*After Satterlee.*

Practical Units of Light.—1 *Candle-power* (British and U. S. standards) is the light of a spermaceti candle ⅞ inch in diameter, burning 120 grains an hour. 1 Meter candle-power is the illumination produced by 1 candle-power at a distance of 1 meter. This is useful as a unit, but the light varies so much under different conditions that more exact standards have been devised for making the actual measurement.

1 *Bec Carcel* (French standard, equal to 9.5 British standard candle-power) is the light of a Carcel lamp burning 42 grammes of pure Colza

oil per hour with a flame 40 mm. high, under conditions fixed by Dumas and Regnault.

1 *Hefner* is the light from a standard amyl-acetate lamp, burning under conditions prescribed by the late von Hegner Alteneck, and equals 0.88 British standard candle-power.

1 *Lux* is the illumination produced by 1 Hefner at a distance of 1 meter and equals 0.88 meter candle-power.

1 *Lumen* is the unit of flux of light in a beam subtending unit of solid angle where the source has an intensity of 1 Hefner; 1 hemispherical lumen, for instance, is the light radiating through a hemisphere of space from a source of 1 Hefner.

The Legal Standard of Light.[1]—The unit of each simple light (blue, green, etc.) is the quantity of the light of the same kind emitted in the normal direction by a square centimeter of surface of molten platinum at the temperature of solidification. The practical unit of white light is the total quantity of light emitted normally by the same surface.

The Author's Units of Light Measured Photographically.—1 *Tousey* is a light or other radiation which will produce the same effect upon Kodak film as 1 candle-power of carbon filament incandescent light of the standard brightness.

1 *Tousey meter second* equals the effect produced as above in one second at a distance of 1 meter.

N. B.—In applying this photographic measurement to x-rays or radium rays, in comparison with incandescent electric light, the film should be developed in the regular tray-developing solutions for ten minutes and in complete darkness.

The Tests Which are Applied to Electric Lights, Either Arc or Incandescent Lamps.—In the case of an incandescent lamp it is of importance to test its resistance when cold. For this purpose the Wheatstone bridge and the current from one or two voltaic cells are employed.

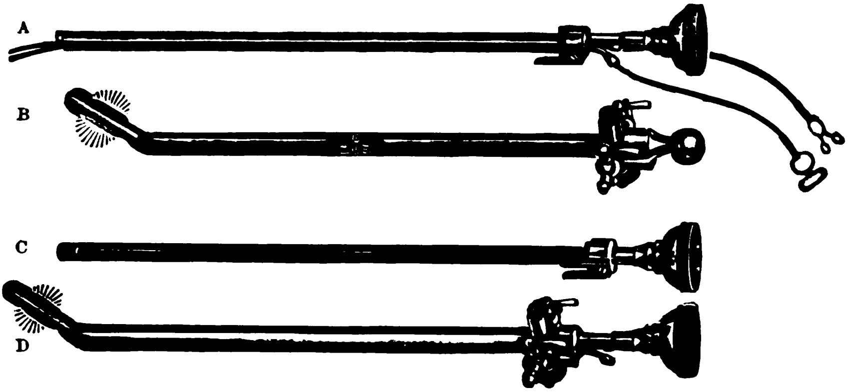


Fig. 393.—F. Tilden Brown's cystoscope.

The process of testing a lamp at work employs a voltmeter on the principle of an amperemeter of very high resistance for measuring the difference in potential between the lamp terminals. The lamp may

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[1] Paris Congress, April, 1884.

be any sort of an electric lamp: incandescent, arc, or vacuum tube. An amperemeter is also required for measuring the strength of the current, which may be turned on or off by the key. A storage-battery or a large battery of voltaic cells may be used instead of the dynamo.

The number of candle-power produced by the lamp must be tested by a suitable photometer. One of the simplest and most accurate is familiarly known as the grease-spot photometer. A sheet of paper with a grease-spot in the center is held up between the standard candle and the light to be tested. Looking at one side of the paper the spot, which has been made partly transparent, appears bright if the light falling upon it from behind is more powerful than the light falling upon the front of the paper around the spot. The paper is moved back and forth between the two lights until the grease-spot appears neither darker nor lighter than the surrounding paper. Both sides are examined to make sure of this. Then the distances from the paper to the standard candle and to the lamp are measured and the number of candle-power varies directly as the square of the distance at which equal illumination is produced. Thus, if the paper is four times as far from the lamp as it is from the standard candle the lamp is giving a light of 16 candle-power.

Knowing the *number of volts* of electromotive power E in the difference of potential at the terminals of the lamp and the current C in *amperes* we have the following formulæ:

$$\text{Resistance (hot) of the lamp in ohms} = \frac{E}{C}$$

$$\text{Electric energy in Watts consumed by lamp} = E \times C$$

$$\text{Watts per candle-power} = \frac{E \times C}{\text{c. p.}}$$

(c. p. = number of candle-power.)

The smaller the number of Watts per candle-power, the higher is the efficiency of the lamp, and for the same type of lamp the less heat is produced with equal illumination.

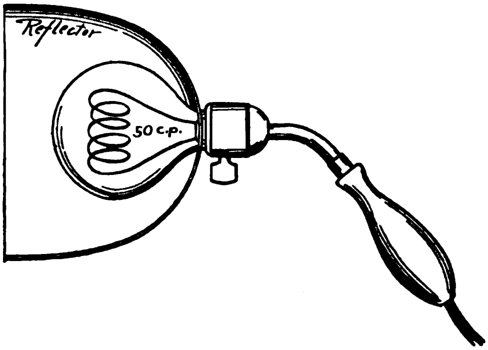

Fig. 394.—Incandescent lamp and reflector.

The modern "cold clamps" for cystoscopic and other endoscopic work are simply incandescent lamps of high efficiency.

Incandescent Electric-light Therapeutic Lamps.—The most common type of apparatus for the application of light is an incandescent lamp mounted in some sort of a reflecting device. Fig. 394 shows a device of this kind in which the lamp used is of 50 candle-power.

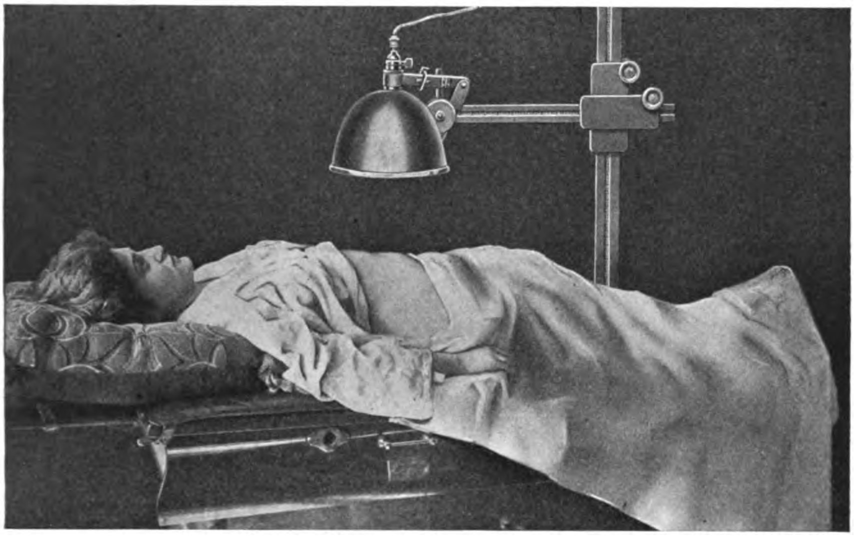

Fig. 395.—Treatment of patient with 100-candle-power lamp and parabolic reflector.

These lamps are made to operate on the 110- or 220-volt current, which may be either direct or alternating. Fig. 395 shows the application of such a lamp. The advantage of this particular device is that it can be easily adjusted to any lamp outlet, and can be held either by the physician or, in some cases, by the patient. This style is useful in muscular pains due to cold, such as what is commonly known as

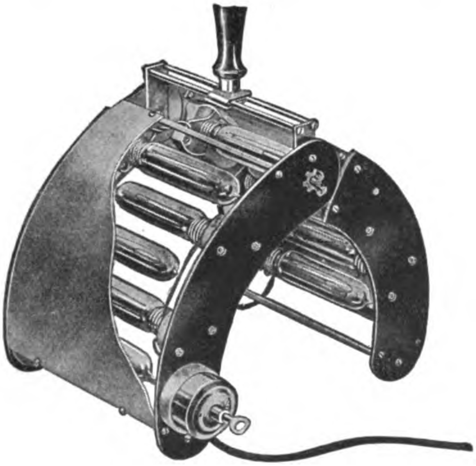

Fig. 396.—Local electric-light bath.

muscular rheumatism. It is also useful in mild cases of neuralgia. Different sizes of lamps of this type are made with incandescent bulbs of

Fig. 397.—Showing a shoulder treatment by electric-light bath.

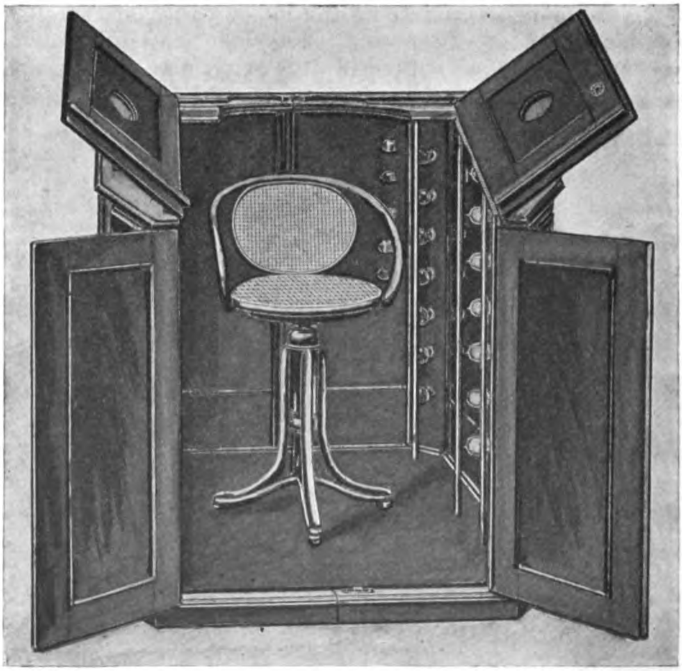

Fig. 398.—Electric-light bath cabinet, open.

various power, and may be used with or without color screens and with different colored bulbs.

Fig. 396 illustrates a slightly more elaborate device for applying the light over a much larger area. In this device there are ten incandescent lamps each of 16 candle-power. It is hinged at the central part so that it can be easily placed around a limb or over the shoulder. On the top of it is a selector switch, so that five or ten lamps can be used, according to the requirements of the case.

Fig. 398 shows an electric-light bath cabinet. This is arranged so that the entire body, with the exception of the head, is subjected to the influence of from forty to eighty incandescent lamps. On the outside of the cabinet is a switchboard so that various sets of lamps can be used. Although the illustration does not show it, there should be an arrangement holding two strips of colored glass, one of red and one of blue, so arranged that either color can be turned in front of the rows of incandescent lamps or, if desired, turned out of the way entirely so that the plain white light is used.

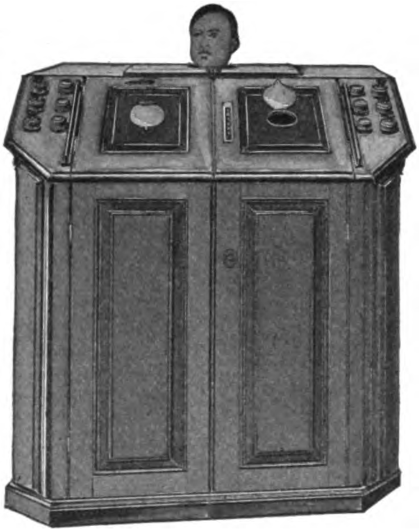

Fig. 399.—Electric-light bath cabinet, closed.

Fig. 400 shows a different style, in which the patient is placed in a reclining position. The number of lights is regulated by means of selector switches on the outside of the cabinet.

Fig. 401 illustrates a portable electric-light cabinet having a folding frame and curtains. This makes a very convenient arrangement, as when not in use it does not take up any space. To this can be easily added the red and blue glass screens. The patient feels much more comfortable than with his head fastened by a wooden or iron cabinet.

Fig. 402 shows a combination cabinet in which are placed a number of incandescent lamps, and on the outside are mounted three arc lights, the object of this arrangement being to obtain whatever benefit there

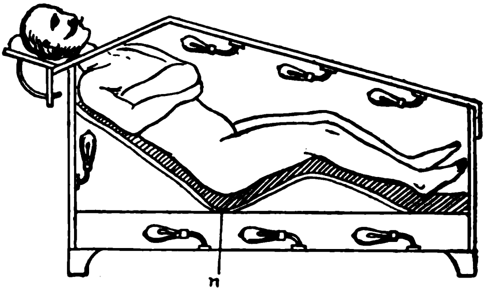

Fig. 400.—Electric-light bath for recumbent position.

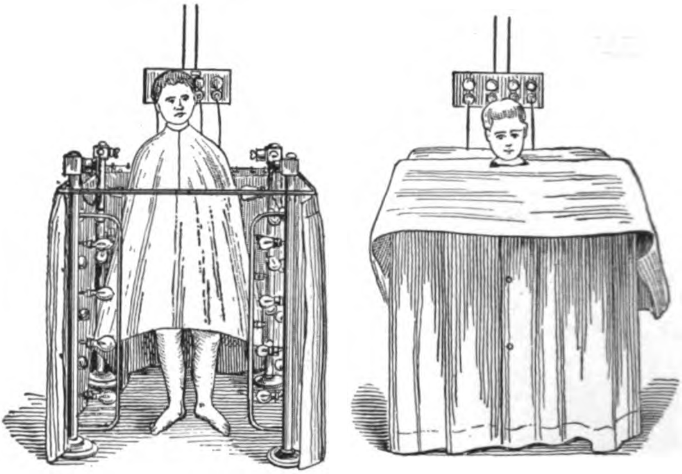

Fig. 401.—Beez portable electric-light bath.

Fig. 402.—Combined incandescent and arc-light bath.

may be from the increased quantity of chemic rays which come from an arc light.

Fig. 403.—Therapeutic lamp with four 125-candle-power incandescent bulbs.

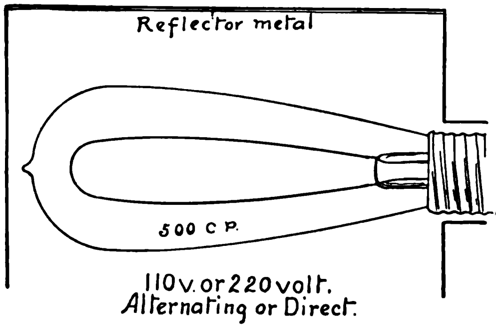

Fig. 404.—500-candle-power incandescent lamp with non-focusing reflector.

Fig. 403 shows an arrangement holding four 125-candle-power lamps, so as to make up a total of 500 candle-power. It is also arranged so that in place of using all the lights, any one or a combination may be used as desired.

Figs. 404 and 405 illustrate an arrangement by which a 500-candle-power lamp is placed in a horizontal position so that the patient receives the direct radiation from the entire length of the filament and the reflector. The rays are rendered parallel, not brought to a burning focus.

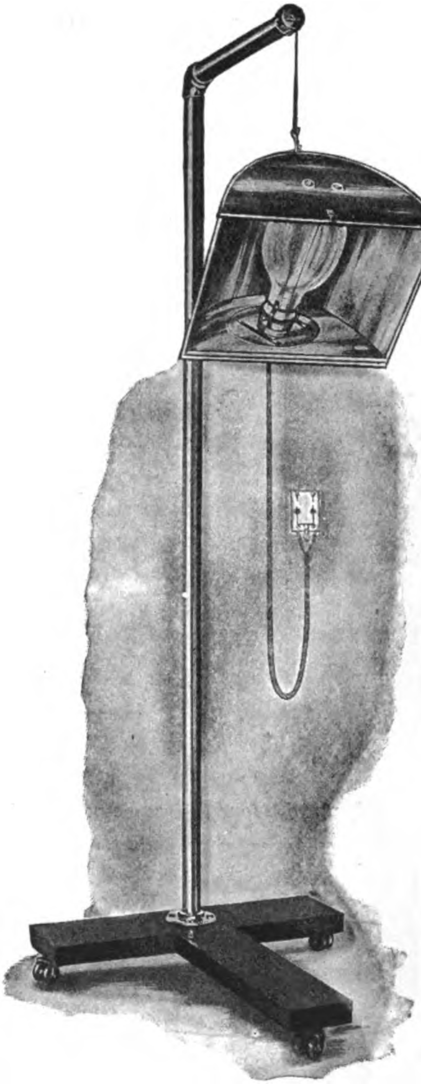

Fig. 405.—Incandescent lamp (500 candle-power) with straight filament in the axis of the reflector. Parallel rays of heat and light are produced. They are not brought to a burning focus.

Colored Screens.—When colored screens are used, they are generally made of narrow pieces of glass held together in a metal frame (Fig. 406). The object of this is to prevent breakage, as the amount of heat absorbed in the glass would break it if it was made of one piece.

Isolation of Calorific Rays of Great Wave-length by Quartz Lenses.[1]—The hot light from a Pintsch lamp passes through a circular opening in a metal screen, then 26 cm. further through a quartz lens and another diaphragm and a second quartz lens, all at the same distance apart. The lenses have a focal length of 27.3 cm. for visible rays; their diameter is 7.5 cm., thickness at edge, 0.3 cm., and at middle, 0.8 cm.; diaphragms are 15 mm.; the central parts of lenses are covered with black paper 25 mm. The greatest wave-lengths are more highly refracted, and pass through the different diaphragms and may be demonstrated by a radiometer.

Fig. 406.—Ray screen for treatment with colored light.

Extremely great wave-lengths up to 300 mm. have been isolated by H. Rubens and O. von Baeyer[2] from the light produced by a mercury vapor lamp filtered through black paper.

Electric Arc Therapeutic Lamps.—Fig. 407 illustrates the original Finsen arc-lamp arrangement. In order to protect the eyes of the assistants from the irritating effect of the chemic rays, they use blue glasses. The apparatus contained an electric arc which used 80 amperes; this has been improved and simplified, the most important modification being one in which practically all the heat rays are absorbed, so that the action is due entirely to luminous rays,the chemic rays which accompany luminous rays, and some ultraviolet rays. The condenser is made of quartz, which allows practically all of the ultraviolet rays to pass. The metal section is filled with water; the section nearest to the arc is arranged for a continual circulation of water. In addition to this, Dr. Finsen had special compressors made of quartz, which were in firm

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[1] H. Rubens and R. W. Wood, Le Radium, Paris, Feb., 1911, p. 44.
[2] Le Radium, April, 1911, p. 139.

contact with the diseased area. These compressors were also either filled with water or arranged for a continual circulation of water. With a lamp such as is shown in Fig. 408 and which requires 25 amperes of current, the time required for a single treatment is one hour and ten minutes, and, as a rule, improvement is not expected in less than three months.

Numerous modifications of this lamp have been made with the idea of increasing its efficiency.

Fig. 408 illustrates the latest improvement in the Finsen ray lamp. This is known as the Finsen-Reyn lamp. With this apparatus only one case can be treated at a time, but instead of using 80 or 100 amperes for the arc, the apparatus requires only 20 or 25 amperes. It has an automatic arrangement for maintaining the arc and an adjustment, so that the length of the arc can be regulated. It is mounted on a heavy iron pedestal and arranged with a counterweight, so that it can be easily raised or lowered and brought into the most convenient position. In this apparatus the lenses are made of quartz, so that all the ultraviolet rays which are generated by the arc are transmitted to the patient with very little loss.

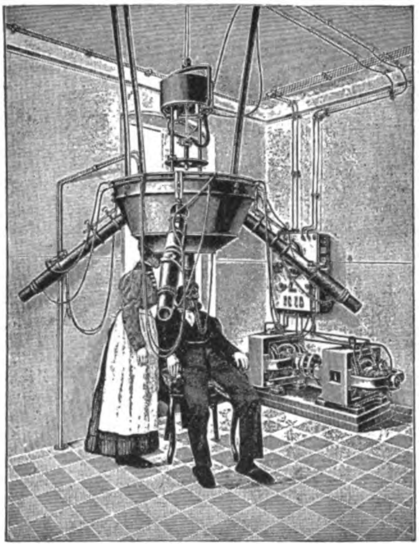

Fig. 407.—Original Finsen lamp. 80 amperes.

Fig. 409 illustrates one of the best forms of arc-light apparatus made in this country; all the adjustments are easily made. The automatic arrangement for maintaining the arc is particularly nice, and requires practically no attention upon the part of the operator. There is a blue glass window so that the arc can be readily seen without discomfort to the observer. This lamp is made to take from 10 to 30 amperes, according to the special requirements of the case.

The small diagrams illustrate the three ways in which the rays can be reflected: Fig. 410, *a*, shows the arrangement for focusing the rays upon a particular point; Fig. 410, *b*, shows the arrangement to cause the rays to diverge; Fig. 410, *c*, to throw all of the rays into one parallel beam.

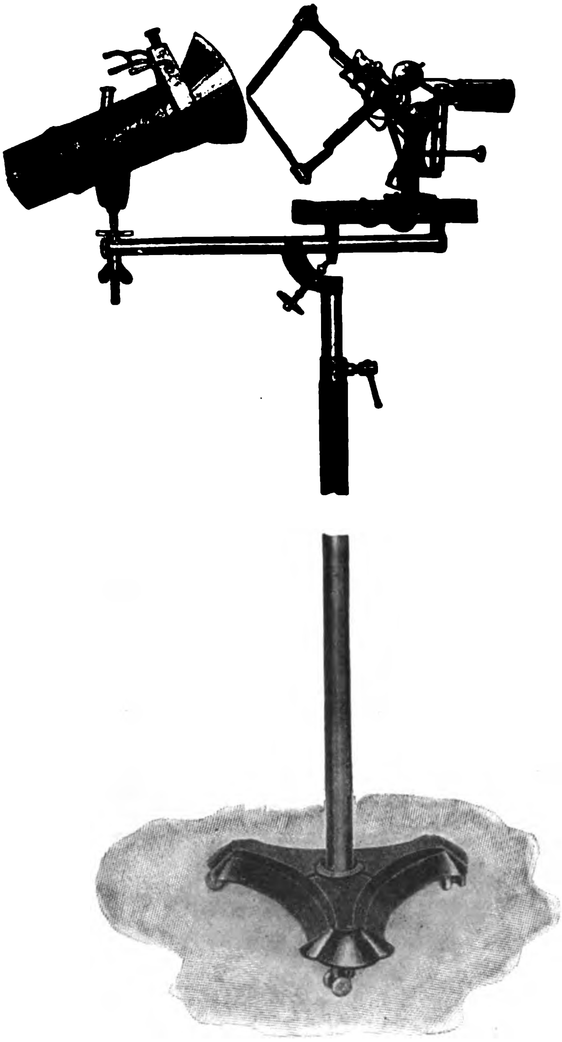

Fig. 408.—Finsen-Reyn lamp.

Iron Electrode Lamps.—It was found that by employing electrodes which were made of iron instead of carbon the proportion of ultraviolet rays was very much increased, and a lamp of this style is shown by Figs. 411 and 412. This was devised by Dr. Bang, and in order to operate it, it was found necessary to have the electrodes and the entire casing arranged for a continual circulation of water. While this device is very efficient, it is a rather inconvenient one to use.

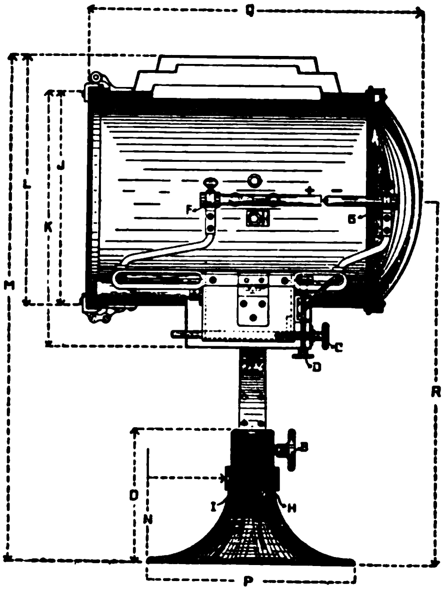

Fig. 409.—Bogue's arc lamp for therapeutic use.

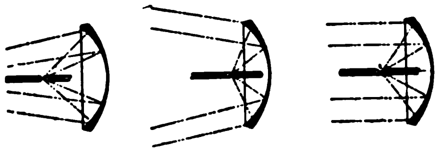
a *b* *c*

Fig. 410.—*a*, Arc too far away from mirror; *b*, arc too close to mirror; *c*, arc in focus.

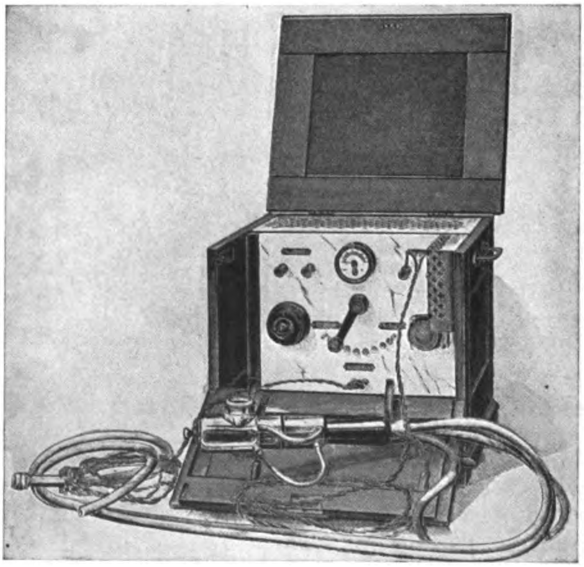

Fig. 411.—Iron electrode arc lamp, water cooled.

Fig. 413 illustrates a modification of the Bang lamp. This was devised by Dr. Henry G. Piffard, of New York City, and its construction is such that no water circulation is required. Owing to the fact that the arc is only 3 inches away from the tissue to be treated, it makes a most efficient apparatus. Iron electrodes, however, cannot be used on an alternating current, so that in order to use this lamp on an alternating current carbon electrodes which have iron filings in them are used.

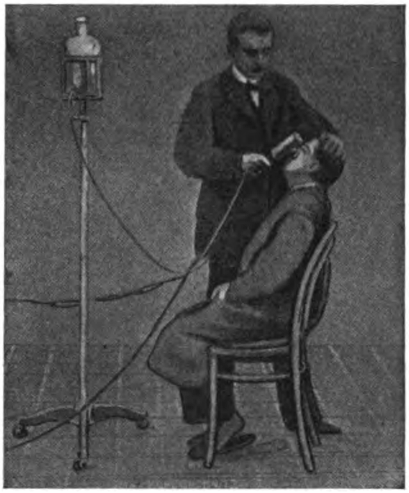

Fig. 412.—Application of water-cooled iron electrode arc lamp.

The carbon arc is not nearly so rich in ultraviolet rays as the iron arc, and this is very prettily demonstrated by the following experiment: Place a piece of solio paper in front of the carbon arc for one minute. You will notice that it will become slightly discolored; now place another piece of solio paper in front of the iron arc, and in the same time you will find that the paper has become absolutely black, this indicating that with the iron arc a greater proportion of chemic rays are generated.

Condenser Spark-gap Lamps.—One therapeutic and physiologic use of condenser discharges is in the production of visible and ultraviolet rays. A Leyden jar 2 inches in diameter and with a total length of 10 inches may have one armature connected with one pole of an induction-coil or transformer regulated to give a spark about 4 inches long. The other armature of the jar is connected with the other pole of the coil or transformer. Besides the above connections an insulated conducting cord passes from each pole of the coil or from each of the Leyden jar

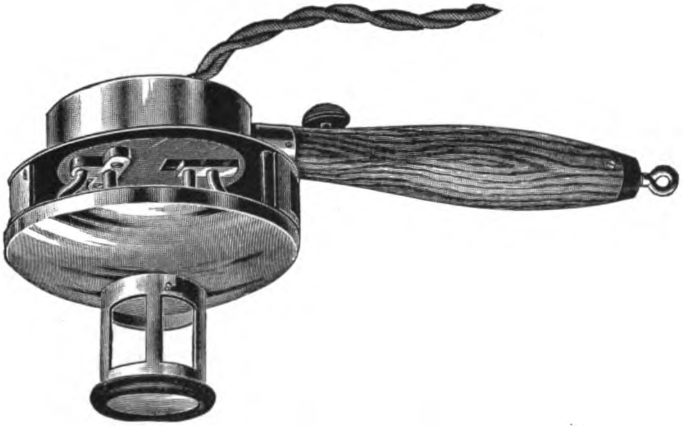

Fig. 413.—Piffard's hand arc lamp for phototherapy.

armatures connected with it to each terminal of a series spark-gap made up preferably of iron knobs. The sparks are very much louder and more brilliant than they would be if the discharge from the coil passed through the series gap unmodified by the condenser. The light is very rich in ultraviolet rays.

Such a lamp has been made with magnesium knobs, but this metal volatilizes readily and a constant shower of sparks is produced which unfits it for this use, although the light produced is especially rich in ultraviolet rays.

About the time that the iron arc devised by Dr. Bang was introduced, Dr. Görl described a lamp based upon this principle for the production of ultraviolet rays. A lamp of this character is the richest source of ultraviolet rays that we have at the present time.

As originally constructed it was rather inconvenient to use, and Dr. Henry G. Piffard, of New York City, devised an improvement in its construction. Fig. 414 illustrates this improvement, which consists in making the spark-gap so that the distance between it and the patient is adjustable. In addition, there is a handle on the side of it, so that the operator can easily and safely handle it. Dr. Piffard now uses this lamp without the quartz window, as was used in the original lamp, as he finds that it is very much more active without the quartz window. He was led to use it in this way by noting the difference in time that an electroscope discharges when the rays from this lamp are directed upon it; when the quartz window is in front of the lamp it discharges the electroscope slowly; when the quartz window is removed the electroscope is discharged instantly, thus showing that there is a radiation from this lamp which the quartz does not transmit. An exposure of five minutes with this lamp produces a very intense hyperemia.

Fig. 414.—Görl ultraviolet ray lamp, modified by Piffard.

Ultraviolet Rays of Exceedingly Short Wave-length.—P. Lenard and C. Ramsauer[1] have discovered rays of less than 90 mu. wavelength in the light from a condenser spark-gap with a tremendously powerful current. They use an induction coil, in which the primary is of copper wire 3 mm. in diameter, around an iron core 110 cm. long and 9 mm. diameter. There are three layers of 330 turns each. The secondary is divided into four sections, in each of which are 32 layers of copper wire 1 mm. in diameter, and there are 90 turns in each layer. The primary will stand a current of 90 amperes for fifteen seconds. The primary

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[1] Le Radium, 1911, p. 115.

condenser has a variable capacity of 6 microfarads. There is a Wehnelt interrupter with a nickel electrode and a jar holding 60 quarts of liquid. There is a secondary condenser in shunt to the spark-gap. The spark-gap has aluminum terminals 7 mm. in diameter and are only 0.8 mm. apart. The current regularly employed is 60 amperes and 200 volts. The energy at each discharge is 1000 times that of the uniform flow of an arc lamp.

The light from such an apparatus is relatively weak in visible rays, but very rich in ultraviolet rays, especially those of the shortest wave-length, even as short as 90 mu.

Fig. 415.—Mercury vapor lamp.

Ultraviolet rays have the property of causing certain chemicals and minerals to fluoresce. The most common test for the presence of ultraviolet rays is the fluorescence they produce when falling upon a piece of Willemite. When the ultraviolet rays strike a piece of Willemite, they cause a most beautiful green fluorescence. In order to determine whether the fluorescence is due to ultraviolet rays, it is only necessary to place a piece of glass between the Willemite and the source of radiation. If the fluorescence is due to ultraviolet rays, the glass will cause the fluorescence to disappear entirely; if, however, the apparent fluorescence is due to the blue-violet color of the light, then the putting of the piece of glass between the source of light and the Willemite will not cause the apparent fluorescence to diminish. Another simple way of testing is to take a piece of solio paper and put a piece of glass over part of it and expose the covered and uncovered portions to the source of light. If the radiation is principally ultraviolet, the solio paper uncovered by the glass will blacken in a short time, whereas the paper under the glass will be hardly discolored. Now in place of the glass put a piece of quartz, and you will find, if the radiation is principally ultraviolet, that the paper under the quartz will be nearly as black as the paper not covered by the quartz.

Fig. 416.—Mercury vapor lamp in use in a case of pulmonary tuberculosis.

Fig. 415 illustrates a Cooper Hewitt mercury vapor lamp as used by the author. The light from this lamp contains no red rays. It is a 450-candle-power light when run by the 110-volt direct current with a rheostat to reduce the current to 4 or 5 amperes.

Fig. 416 shows this lamp in use in the treatment of a case of pulmonary tuberculosis.

A modification of this lamp is what is known as the uviol lamp (Fig. 417). This is also a mercury vapor lamp, but instead of using ordinary glass the glass used is one which will transmit higher frequencies of vibration and hence more of the ultraviolet ray than the ordinary glass. This has been used in Europe, but it is too early to state what its therapeutic value will be.

Kromayer's Mercury Vapor Therapeutic Lamps.—Professor Kromayer, of Berlin,[1] has devised mercury vapor lamps of suitable form and dimensions for contact application in the treatment of the skin or of the mucous membrane of the mouth, urethra, etc. The tube carrying the incandescent mercury vapor is made of quartz, so as to transmit

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[1] Münch. Med. Woch., 1906, No. 10, p. 577, reviewed in Le Radium, April, 1906.

the ultraviolet rays freely. This is enclosed in a metal case or a glass tube, according to the use to which the lamp is to be put. In either case there is a circulation of water between the lamp and the outer case and the portion through which the light is to be applied to the patient is also made of quartz. Two types of lamp are made; one is of high voltage (120 to 150) and low amperage (3 to 4); the other is of low voltage (150 to 200) compared with its amperage (2 to 20). The advantages claimed for it are that it has from three to five times as great penetration as the Finsen (arc lamp with carbon electrodes) and a greater superficial action than the dermo arc lamp with iron electrodes.

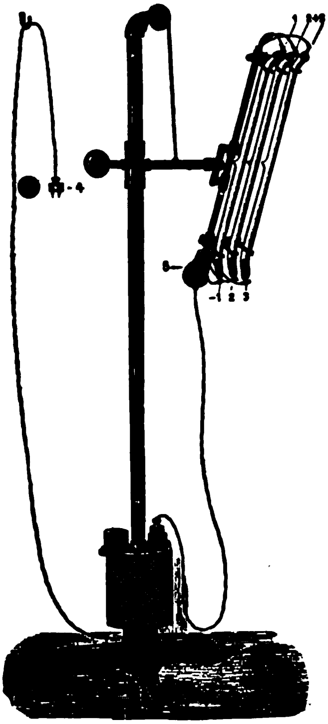

Fig. 417.—Uviol lamp.

Therapeutic Lamps for Internal Use.—Vacuum light tubes have been devised by Strebel[1] for introduction into the cervix, the urethra, or the mouth for the therapeutic effect of light.

The Nernst Lamp.—Fig. 420 shows the latest high-efficiency incandescent lamp, which was discovered by Dr. Nernst. This differs from the usual incandescent lamp in that the incandescent filament is not enclosed in a vacuum, but exposed to the air. Apparently this lamp is going to be one of the most efficient of the incandescent style used for therapeutic purposes, as the actinic power is great and the heat is very much less in proportion than when the usual incandescent lamps are used.

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[1] Dermatol. Zeitschrift, vol. xi, p. 77.

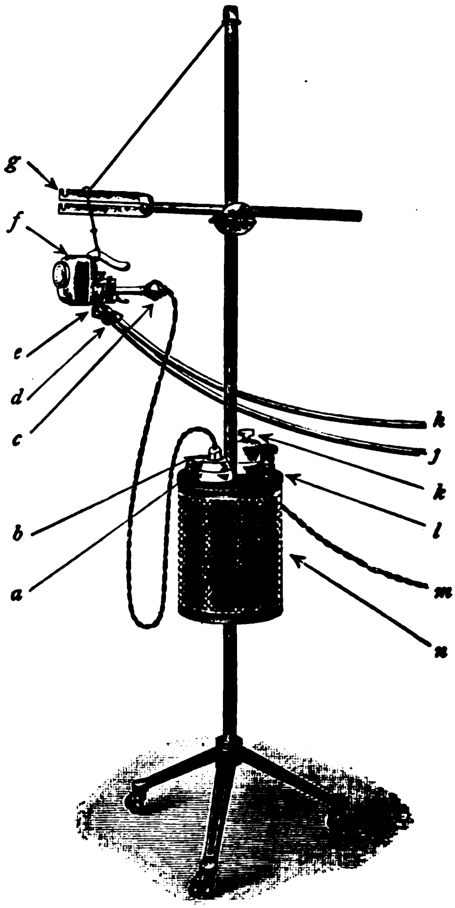

Fig. 418.—The Kromayer lamp: *a*, Lamp connection-plug; *b*, current direction-indicator; *c*, plug connection; *d*, tube connection; *e*, winged nut for fixing lamp in fork *g*; *f*, Kromayer quartz lamp; *g*, fork lamp-holder (may be fixed.in any position); *h*, *j*, in- and outlet for cooling water; *k*, switch; *l*, rheostat lever; *m*, line connection; *n*, rheostat (Hanovia Chemical and Manufacturing Co., Newark).

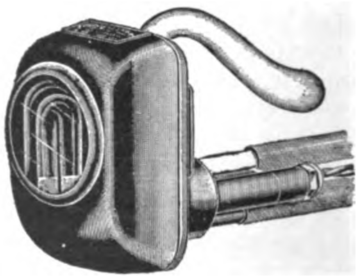

Fig. 419.—The Kromayer lamp (Hanovia Chemical and Manufacturing Co., Newark)

As this is also a new type of lamp, it has not been used sufficiently to give an idea as to what its ultimate therapeutic value will be; the only disadvantage is that it can only be operated satisfactorily on the alternating current at the present time. The heater coil of platinum wire alone transmits current at first and, becoming incandescent, heats the glower, which is a small rod of such materials as zirconium and thorium.

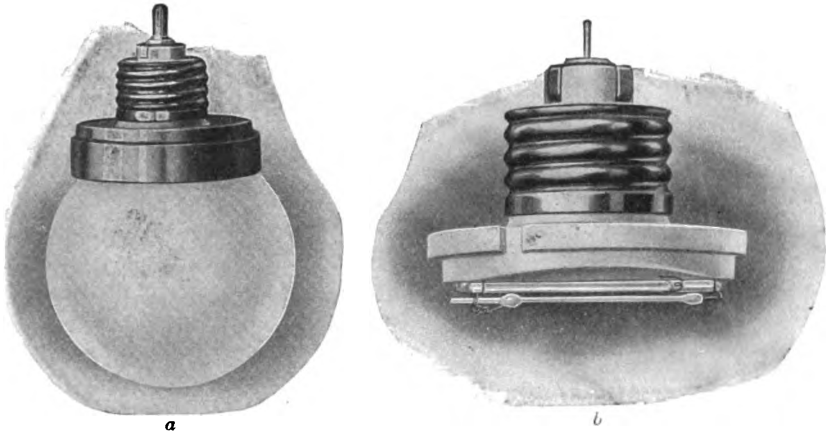

Fig. 420.—*a*, Westinghouse-Nernst lamp; *b*, Westinghouse-Nernst lamp, with globe removed (heater and glower).

This becomes a conductor of electricity when hot, but though its resistance is diminished, it is still so great that it becomes incandescent itself.

Ultraviolet rays are generated by a Crookes tube or an *x*-ray tube, and a special construction has been devised by H. Bierry, Victor Henri, and Albert Ranc.[1] The tube has a sort of pocket of quartz tubing in which substances may be placed very near the anticathode. Carbohydrates undergo the same changes as when exposed to the ultraviolet rays from a mercury vapor lamp. A burn appearing within twenty-four hours after an *x*-ray exposure is doubtless due to ultraviolet rays generated by the *x*-ray tube. This source of injury may be suppressed by interposing any screen opaque to ordinary light.

Effects of Ultraviolet Rays Upon Gases.—1. There are produced uncharged centers of condensation which are due to impurities in the gas.

2. Both positive and negative ions are produced in the gas.

3. There may be changes in the gas itself, as when oxygen is changed to ozone.

The effect upon chlorin has been especially studied by Ludlam,[2] who finds that the presence of a trace of chlorin increases the ionization of the air under the influence of ultraviolet rays, but that above 1 per cent. the more chlorin is added the feebler the ionization becomes.

The *ultraviolet rays in sunlight ionize the air*, rendering it a conductor of electricity, and, as might be expected, Dember[3] has found that this

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[1] C. R. de la Societe de Biologie, lxx, 523, April 1, 1911.
[2] Phil. Mag. we, 1912, 757.
[3] Phys. Zeitschr., 13, 1913, 207.

effect was proportionately greater at a mountain top where the dust in the air has had much less chance to reduce the amount of ultraviolet radiation.

Ultraviolet Rays Ionize Dielectric Liquids and Some Dielectric Solids.—Soft rubber, which is ordinarily such a good insulator, is immediately disintegrated and ceases to be a non-conductor of high-frequency currents; it is, therefore, useless for insulating wires transmitting these currents. The ultraviolet rays in this case come from the shower of sparklets covering the surface of the wire and which may be seen if the outer surface is touched with the finger. The same sparklets may be drawn from a glass insulated covering, but glass is not affected by the ultraviolet ray.

The light from a Geissler tube ionizes neighboring gases.

An insulated sheet of aluminum acquires a positive charge when exposed to the ultraviolet ray.

PRINCIPLES OF PHOTOTHERAPY

Sunlight is universally recognized as a powerful bactericide. Tubercle bacilli were destroyed in Bang's experiments by a six-minute exposure to the non-concentrated light from a 30-ampere arc lamp at a distance of 30 cm. (12 inches), and Jansen and Busch and Nagelschmidt have shown the destructive effect of ultraviolet rays upon tubercular and pneumonia germs inoculated in the living skin or cornea. Klingmuller and Halberstädter found, however, that small pieces of lupus tissue exposed to the Finsen lamp for seventy minutes still produced tuberculosis if injected into a rabbit's peritoneum.

The effect of phototherapy, which is the most striking modern discovery, is in the cure of lupus vulgaris. It is not probable that the effect is due simply to a direct bactericide effect. Other factors are the generation of hydrogen peroxid, ozone, and oxygen in tissues exposed to ultraviolet light and the development of new-formed connective tissue whose fibers compress and destroy the tubercular foci.

The *blood-pressure* is low in the tropics, due probably to a vasodilatation from the heat. This has an important bearing upon tropical pathology.[1]

Effect of Variously Colored Lights.—Colored lights have different effects. The red light, for instance, is stimulating, whereas the blue light is depressing. Dr. Nils R. Finsen, who proposed the use of the arc lamp for the treatment of certain skin diseases, called attention to the fact recorded by Picton, of New Orleans, almost a century previously, that cases of smallpox did very much better when the ordinary luminous rays were kept from the patient. This was accomplished by means of red glass, which also cut off most of the ordinary chemic rays. In order to obtain the effect of different colors the glass of which the incandescent lamp is made can be of the desired color, or a glass of the desired color can be placed in front of the incandescent lamp, which is made of the ordinary colorless glass. The colored glass does not add any property to the original light; it simply cuts off all other colors. It does not do this absolutely, but it does so for all practical purposes, and the action of a blue glass placed in front of the light will be just the same as though the incandescent lamp were made of blue glass.

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[1] W. E. Musgrave and A. G. Sisson, Philippine Jour. of Science, v, 225, 1910.

It is a well-known fact that light favors oxidation outside of the body, and as it penetrates the body it should and undoubtedly does promote oxidation and chemic changes in the fluids of the body. According to Freund, light is capable of changing a passive congestion into an active one, so that light is indicated in chronic congestive conditions where the light can be applied in sufficient power.

Chemic Effects of Ultraviolet Rays.—Ultraviolet rays bring about loss of nitrogen in certain chemic compounds and in others the reverse, changing nitrates to nitrites or vice versâ.[1]

Ultraviolet rays change starchy solutions into maltose and dextrin[2] and, according to the same experimenter, inulin is changed into glucose and levulose.

Ultraviolet rays destroy the properties of diastase in solution. Rays of a wave-length greater than 3022 Angström units do not have this effect.[3]

Effect of Ultraviolet Rays Upon the Digestibility of Milk.—A short exposure has no effect, a longer exposure lessens tryptic digestibility, and a still longer exposure restores it.[4]

Ultraviolet rays change saccharose into glucose and levulose; their more prolonged action produces formaldehyd and carbonic oxid.[5]

Ultraviolet rays from a quartz mercury vapor lamp change a small proportion of chlorophyll dissolved in alcohol and water into urobilinogen.[6]

Ultraviolet rays, three hours and a half exposure, destroys the hemolytic action of saponin.[7]

Ultraviolet rays destroy amylase and invertase (in malt and yeast); the former is more sensitive, and in a mixture it may be destroyed and the invertin be only attenuated.[8]

Biochemic Effects of the Ultraviolet Ray.—Ultraviolet rays in thirty minutes to two and one-half hours reduce the toxicity of Strophantines.[9]

Ultraviolet rays quickly destroy the venom of the cobra, but have much less effect upon antivenomous serum.[10]

Ultraviolet rays have an effect upon the Wassermann reaction for syphilis analogous to their effect upon tuberculin. They do not effect the properties of sera rich in antibodies, but antigens and antibodies no longer fix alexins.[11]

Bacteria killed by ultraviolet rays preserve their agglutinins intact, and can be used for serodiagnosis.[12]

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[1] C. R. de l'Academie des Sciences, clii, 522, Feb. 27, 1911.

[2] L. Massol, Ibid., 902, March 27, 1911.

[3] H. Agulhon, Ibid., 398, Feb. 13, 1911.

[4] J. Telarico, C. R. de la Soc. de Biol., lxix, 324, Nov. 5, 1910.

[5] Henri Bierry, Victor Henri, and Albert Ranc, Ibid., lxx, 900, June 3, 1911, and C. R. de l'Acad. des Sciences, 1629, June 6, 1911.

[6] H. Bierry and J. Larguier des Bancels, C. R. de l'Acad. des Sciences, cliii, 124, July 10, 1911.

[7] Tr. Solacolu, C. R. de la Soc. de Biol., lxxi, 204.

[8] A. Chauchard and B. Mazonie, C. R. de la l'Acad. des Sciences, clii, 1709, June 12, 1911.

[9] D. Danielopolu, C. R. de la Soc. de Biol., lxxi, 200, July, 1911.

[10] L. Massol, Ibid., 183, July 23, 1911.

[11] Maurice Breton, Ibid., lxx, 507, April 1, 1911.

[12] H. Stassano and L. Lamatte, C. R. de l'Academie des Sciences, clii, 623, March, 1911.

Ultraviolet rays destroy the antitryptic properties of human blood-serum.[1]

Effect of Ultraviolet Rays Upon Anaphylaxis.—Horse serum, exposed to the radiation for two and one-half to three and one-half hours, shows a destruction of its antisensibilitins without loss of its precipitogenous properties.[2]

Effect of Ultraviolet Rays Upon Tubercle Bacilli and Tuberculin.—A short exposure attenuates the bacilli in a culture and a long exposure kills them. Tuberculin loses its properties, and this effect is more rapidly produced in the air than in a vacuum.[3]

Effect of Ultraviolet Rays Upon Tuberculin and Antitubercular Sera.—It renders tuberculin inactive, but does not modify its precipitogenous property. Serum, however, quickly loses its precipitant property.[4]

Influence of Light in Causing Hyperglobuly at High Altitudes.—The accumulation of blood-cells in the peripheral vessels which ordinarily takes place at high altitudes may, according to T. Gayda's experiments upon rabbits, be prevented by exclusion of light.[5]

The **effects of ultraviolet rays upon micro-organisms** have been exhaustively studied by Mme. V. Henri Cernovodeanu and Victor Henri, at the physiologic laboratories of the Sorbonne and of the Pasteur Institute.[6]

As far back as 1877 Downes and Blunt[7] experimented upon the bactericide effect of light and found that the most refrangible was the most active. Among others Roux, Geissler, and Marshall pursued further studies, which preceded Finsen's work. The latter in 1899 to 1905, with his pupils, S. Bang, V. Bie, A. Larsen, G. Dreyer, H. Jansen. O. Jensen, G. Busck, Schmidt-Nielsen, A. Reyn, and R. Kolster, studied the effect upon yeasts, fungi, amebæ, infusoria, and different animal tissues.

Finsen and his pupils showed that our sunlight is quite poor in ultraviolet rays, due to absorption by the air. The arc light is rich in ultraviolet rays, and with the positive carbon 24 and the negative 12 mm. in diameter and 35 to 80 amperes, with an average of 50 volts, the light being concentrated upon a surface 12 mm. in diameter by a quartz lens 7 cm. in diameter, and with the heat filtered out by a layer of water in a vessel with quartz walls, this light kills the Bacillus prodigiosus in two or three seconds. Arc lamps with metallic electrodes, especially iron, are many times more effective than those with carbons.

The interposition of even a thin sheet of glass, and the admixture of bouillon, pepton, albumin, gelatin, or any other organic colloids to the water, arrests the major part of the ultraviolet rays, while perhaps perfectly transparent to the visible rays. Various germs show different degrees of susceptibility, young cultures are more sensitive than old ones, and the spores are three to five times as resistant as the germs. But cultures of any of them may be sterilized by exposure to the ultraviolet ray. The time required is from a few seconds to a few minutes.

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[1] M. Weinberg and M. Rubinstein, C. R. de la Soc. de Biologie, lxxi, 258, July 29, 1911.

[2] V. Baroni and C. Jennesco-Migaiesti, Ibid., lxix, 273, Oct. 22, 1910.

[3] V. Henri-Cernovodeanu, Victor Henri, and V. Baroni, C. R. de l'Acad. Sciences, cli, 724, Oct., 1910.

[4] A. Jousset, C. R. de la Soc. de Biol., lxix, 459, Nov. 26, 1910.

[5] Archives Italliennes de Biologie, liv, 197, 1911.

[6] Journal de Physiologie et de Pathologie generale, xiii, 1911, 865.

[7] Proceedings of the Royal Society, 26, Dec., 1877.

These experiments also showed that the effect was due directly to the light, and takes place in the absence of heat or oxygen.

A later development dates from 1905, with the discovery of the sensibilization of animal tissues by means of substances like anilin dyes containing iodin or bromin, which is liberated in the tissues by the ultraviolet ray and adds to the effect. For example, a hypodermic injection of 2 milligrammes of hematoporphyrin into a white mouse produces no inconvenience while in the dark, but kills in three hours' exposure to arc light.

And the final process consisted in the introduction of the mercury vapor arc in a tube of quartz, like Kromayer's, generating the ultraviolet ray much more powerfully than any of the open arc lamps.

The therapeutic use of the ultraviolet ray is due to Finsen, Preisz, Seiffert, and others, who applied it to the sterilization of milk, and Courmont and Nogier to the sterilization of considerable quantities of water.

It has long been known that the most rapid vibrations among the ultraviolet rays are the most active, and Thiele and Wolf[1] proved this by the use of a screen of blue rock salt, which arrested the heat rays, the visible rays, and the ultraviolet of a wave-length greater than 330 mu., but which was perfectly transparent to ultraviolet rays of a wavelength from 330 to 219 mu.

Measurement of the Intensity of the Ultraviolet Rays.—The intensity of the different wave-lengths generated by an ultraviolet lamp may be measured by a delicate thermopyle and a quartz lens or differently absorbent screens. A relative measure of the entire ultraviolet radiation is obtained by measuring the ionization of gases and electrification of metallic surfaces very much as radio-activity is measured. Becquerel's method, modified by Eder, is based upon the amount of calomel precipitated from a mixture of ammonium oxalate and bichlorid of mercury.[2]

The sterilizing effect upon a twelve- or twenty-four-hour-old culture of colon bacilli upon agar is employed by Henri Cernovodeanu and Henri (l. c.). The bacilli are carefully scraped off without any lumps of agar and are emulsified in distilled water and exposed at a distance of 20 cm. from the lamp. This reaction is almost exclusively limited to the invisible ultraviolet rays, and the interposition of a sheet of colorless glass 1 mm. ($\frac{1}{25}$ inch) thick makes it take 1000 or 2000 times as long to sterilize the emulsion of bacilli. An exposure of one second with a certain mercury vapor lamp with 140 volts and 4.7 amperes produces complete sterilization, while 300 seconds are required with 23 volts and 2.3 amperes. The photographic effect upon nitrate of silver paper (solio matt) is employed by the same authors. This paper, when exposed to the light from a mercury vapor lamp, is chiefly acted upon by the ultraviolet rays, only one-eighth of the effect being due to the visible rays.

The time required to produce an equal discoloration is inversely proportional to the bactericidal activity. A means of arriving at the proper color of the paper is by comparison with the action upon iodid of potassium. Henri-Cernovodeanu and Henri place 9 c.c. of 5 per cent. solution of 25 per cent. sulphuric acid in a glass dish, 3 cm. in diameter, at a distance of 20 cm. below the lamp, and determine the time required to liberate 0.15 milligramme of iodin.

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[1] Arch. für Hygiene, 59, pp. 29–55, 1906.

[2] Eder. Acad. Vienna, October 16, 1879.

Water is very transparent to the ultraviolet ray, even more so than air, and through either medium the time required to produce an equal effect increases about as the square of the distance from the lamp.

The bactericidal effect is neither slowed nor hastened materially by the temperature at which the ultraviolet ray is applied. In this it follows Goldberg's law regarding true photochemic reactions.[1] This is entirely contrary to ordinary chemic reactions, which are many times more active at high temperature.

The bactericidal effect of ultraviolet rays is the same whether the emulsion is a liquid or is frozen into ice, providing the latter is transparent.

It was formerly supposed that the bactericidal effect of the ultraviolet rays was due to peroxid of hydrogen generated by the rays, but bacteria are killed just as quickly in the absence of oxygen or even in a vacuum, and Henri-Cernovodeanu and Henri have measured the quantity of peroxid of hydrogen generated during the few seconds required to sterilize an emulsion of colon bacilli and find it to be an infinitesimal trace.

Different organic substances are variously susceptible to change under the influence of ultraviolet rays. Glucose is much more resistant than levulose, and some fatty acids are more quickly saponified than others. The cancer cells in mice are more susceptible than the normal cells. (Cernovodeanu and Nègre.) The visible effect (with the ultramicroscope) upon protoplasm is coagulation. Micro-organisms of considerable size, like parameces, and the white blood-cells and the white of egg and the blood-plasma, all show this effect when exposed to the ultraviolet rays.

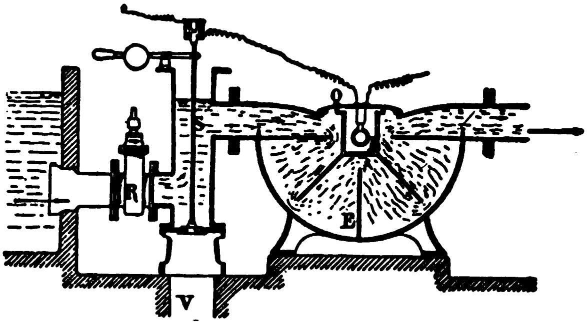

Fig. 421.—Interior view of mercury vapor lamp water steriliser (Evans).[2]

Microbes and animal cells of all kinds are fixed by exposure to ultraviolet rays. Thus, the red blood-cells no longer lose their hemoglobin on the addition of water. The microbes are more difficult to color with different stains; and if the exposure has been prolonged, the microbes undergo granular disintegration. Gram's staining no longer takes effect and the acid resistance of tubercle bacilli is lost.

Sterilization of Water and Milk by the Ultraviolet Rays.—Water, which has been rendered perfectly transparent by filtering, can be

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[1] Zeit. für wiss. Photogr. Photoph. und Photochem., 4, 67, 1906.

[2] Transactions of Illuminating Engineers Society, January, 1914, p. 19. (The Mercury Vapor Quartz Lamp, W. A. D. Evans.)

completely sterilized by passing through an apparatus in which it must come in contact three separate times with the quartz plate separating it from the space in which a mercury vapor quartz lamp is in operation. The lamp in the apparatus shown in Fig. 421 requires a current of 725 watts and will sterilize 130,000 gallons of water per day. Milk cannot be sterilized by the ultraviolet rays except in such thin layers as to be transparent, and no very practicable apparatus is yet in use for this purpose.

The Physiologic Effect of a Local Application of the Ultraviolet Ray.—The effort is chiefly confined to the skin, and consists of an erythema with a papular swelling which often develops into a blister in the course of twelve to twenty-four hours. The blister dries and when the crust falls off no scar is found. Meironsky[1] finds that the ultraviolet light stimulates epithelial cells and increases their metabolism, but strong applications cause degeneration and blistering. There is a congestion of the blood-vessels with emigration of leukocytes and extravasations of blood into the tissues. There is the increase in fibrous tissue cells already noted and a swelling of the connective-tissue stroma. A deposit of pigment granules may take place in all the different layers of epithelia.

Granulating surfaces heal much faster if treated by ultraviolet light.

Blood circulating in the tissues limits the effect of the ultraviolet ray to the most superficial layers of the skin. Finsen blanched the skin by pressing a quartz lens upon it, and others have injected adrenalin or introduced the latter by electrolysis.

Sensibilization of the Tissues to Light.—The tissues may be rendered more sensitive to light rays by the injection of substances like erythrosin. This substance renders the tissues sensitive to the rays, from the greenish-yellow to the yellow-orange inclusive, which ordinarily do not affect the tissues. The effect of a Finsen treatment is thus obtained in one-fourth to one-third the ordinary time. Dreyer[2] introduced the use of this substance following the experiments of Tappeiner and Raab upon protozoa and animal tissues. The value of the method, however, has been seriously questioned.

Eosin has been used in the same way as erythrosin[3] with favorable results in tubercular, syphilitic, and cancerous conditions of the skin. Straub's theory is that eosin generates hydrogen peroxid under the influence of light.

Morton's method of sensibilization of the tissues to light and other radiations by the internal administration of quinin or fluorescin is still *sub judice*, and the author's own observations do not confirm its value.

Sorrentino[4] paints the surface of the lupus with an arseniate, which seems to allow the rays to penetrate the tissues.

Forschhammer[5] used the following solution:

℞.	Erythrosin	1.
	Sodium chlorid	0.85
	Distilled water	100.

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[1] Monatshefte f. Dermatologie, xlii, 1906.
[2] Dermatol. Zeitsch., iv, No. 10.
[3] Tappeiner and Iesionek, Münch. Med. Woch., 1903, No. 47.
[4] Giornale ital. delle malatti vener. i della pelle, 1906, No. 1.
[5] Deutsch. Med. Woch., Sept. 15, 1904.

It was injected 350 times altogether in 23 cases of lupus under phototherapy at Copenhagen. It produced no discomfort until the exposure to the powerful light took place, four to eight hours after the injection. The reaction to Finsen light was very violent, more like a case of phlegmon than like the ordinary reaction after a similar exposure. Experiments with different doses produced either no effect or a most violent one. The therapeutic effect seemed to be bad.

The Effect of Ultraviolet Rays Upon the Eye.—This is a subject which has been studied in detail by Birch-Hirschfeld.[1] The rays in his experiments were from a variety of sources; a powerful arc lamp with carbon electrodes; a *dermo* lamp with iron electrodes; sparks from an electrostatic induction apparatus; sunlight. Quartz lenses were used to concentrate the rays in the eye.

The ultraviolet rays are largely arrested by the crystalline lens, and this protects the retina from any marked effect. An eye from which the crystalline lens has been removed, for experiment or for the cure of cataract, loses this natural protection. The especial changes in the retina from exposure to a powerful arc lamp under these circumstances are a loss of chromatin in the ganglionic cells and the development of vacuoles in the protoplasm of these cells. The nuclei of the same cells are large and clearly defined and have a vacuolar appearance with a very distinct nucleolus. Every other part of the retina is affected to a slight extent. These changes may be noticed at once or may take twenty-four hours to develop. They are recovered from in a few days.

Exposure of the normal eye to the powerful arc lamps used in phototherapy produces also important changes in all the ocular media except the crystalline lens, which remains transparent. There are conjunctivitis; cloudiness of the cornea and partial desquamation and sometimes karyokinesis and vacuolization of its epithelium; iritis and fibrinous exudation in the anterior and posterior chambers of the eye. These conditions disappear after a few days, but slight corneal trouble, hyperemia, and the vacuolization of the ganglionic cells of the retina may remain for a long time.

Sunlight is very rich in ultraviolet rays under certain special conditions. The reflected glare from snowfields upon high mountains in winter affords an example, and the eyes often suffer in consequence.

The ultraviolet rays in the blinding flash of light to which electricians are sometimes exposed from accidental short-circuiting produce important effects upon the eye. There is often temporary blindness lasting a few minutes or a few hours, and sometimes there is erythropsia; all objects, especially bright ones, appear red. After a few hours the conjunctiva becomes red and swollen with a feeling as if the eyes were full of sand. Keratitis and iritis develop. These conditions all disappear in a few days, but in some of these cases there are also changes in the retina which may last for a long time or even be permanent, and which are perhaps not due to the ultraviolet rays alone.

The effect of a stroke of lightning upon the eye is often very severe—the crystalline lens may become opaque (cataract), and there may be atrophy of the optic nerve or slighter nervous changes. These do not appear to be due to the influence of light alone.

Ordinary eyeglasses protect the eye perfectly from the rays which

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[1] Arch. f. Ophthalmologie, vol. lviii, p. 469.

are, strictly speaking, ultraviolet (beyond the visible extremity of the spectrum), but some of the visible rays near the violet end of the spectrum produce similar effects. These rays may be guarded against by smoked glasses or yellow glasses, but not by blue glasses.

The ultraviolet rays destroy bacteria in the eye either in front of or behind the crystalline lens, but the eye would be badly injured by the necessary length and strength of exposure.

Conjunctivitis Due to Electric Light.—This occurs quite frequently among those who regulate or repair arc lamps, and under conditions which make it evident that the trouble is caused by the light and not by the heat rays. We believe also that it is due to the rays at the violet end of the spectrum and to the ultraviolet rays. The affection is only temporary and the treatment is by cold affusions of boric acid solution.

More serious cases have been observed by Fuchs and are complicated by myosis, slight opacities, and erosions of the cornea, but these also are recovered from in a few days. Harold Grimsdale[1] has given detailed reports of several cases. One case was in a workman who had profuse lachrymation and redness and edema of the conjunctiva with several little papules. Vision was notably diminished. He had repaired an arc lamp which remained lighted while he was working at it. Photophobia and the other symptoms enumerated above had come on within a few hours. Rapid recovery followed the use of cocain and cold affusions of boric acid solution. Smoked glasses had to be worn for some time afterward.

Another of Grimsdale's cases followed an instantaneous exposure. An engineer was arranging some incandescent lamps and a short circuit occurred. There was a flash of light lasting an exceedingly short time. The man felt blinded, but was able to see directly afterward. There was severe pain lasting for a few minutes, but toward night all the symptoms had disappeared for the time. He awoke in the night, however, with an intolerable itching of the eyelids, as if their mucous surface were covered with sand. There was lachrymation, but no blepharospasm or marked photophobia. The palpebral conjunctiva was congested and covered with papules. Vision was normal. Cocain and cold affusions of boric acid solution effected a cure in two days.

The present author once performed an experiment in which a heavy steel finger-nail file held in the hand was used to short circuit the 110-volt direct current. There was a wonderful flash of light and about ¼ inch of the steel was actually consumed; not merely melted, but vaporized and dissipated. The author's face was about 15 inches from the powerful arc thus produced, but there was no perceptible effect upon his eyes. Unfortunately, he is unable to recall whether he had eyeglasses on at the time or not. Plain glass does not arrest much of the visible light, but it does stop a great part of the invisible ultraviolet rays, which are highly actinic.

Physiologic Effects of Ultraviolet Ray Baths.—Those baths in which arc lights are the source of illumination give the patient the benefit of the ultraviolet rays as well as of the light rays and the radiant heat.

The effect is a vasodilator one upon the skin and a reduction in general blood-pressure, which is of sufficient duration to make the application valuable in many cardiovascular diseases, including angina pectoris.

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[1] Presse Medicale, April 22, 1902.

The effect of an electric arc-light bath has been studied, principally upon himself, by Hasselbach of the Finsen Institute of Copenhagen.[1] Le Radium, April, 1906, formulates the results of these observations as follows:

1. The cutaneous hyperemia produced by the intense actinic light slows the respiratory movements, and this slowing may persist for several days.
2. This may be caused by partial paralysis of the muscular walls of the cutaneous blood-vessels.
3. The slowness of the respiratory movements is offset by their increased depth, so that the amount of air inhaled per minute is unchanged.
4. The chemic respiratory exchanges are slightly increased the following day.
5. The frequency of respiration even under normal conditions is subject to regulation by variations in the cutaneous vasomotor innervation.
6. Such a light bath generally lowers the arterial tension about 8 per cent., and this reduction sometimes remains for a month after a course of baths.
7. The pulse-rate is increased in some patients and reduced in others.
8. There is sometimes a temporary mental stimulation.

Physiologic Effect of Incandescent Electric-light Baths.—The most marked effects are profuse sweating and superficial vasodilatation which increased tissue changes and lowered arterial tension. As commonly applied the effect is due chiefly to the radiant heat, but there is sufficient evidence that the light itself is also beneficial.

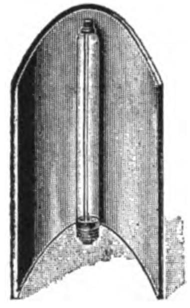

Fig. 422.—Straight filament incandescent lamp with parabolic reflector for concentrated electric-light baths (Wulff's patent. Reiniger, Gilbert & Schall, Elangen).

The Temperature of Incandescent Electric-light Baths.—The statement is sometimes made that electric-light baths at about the temperature of the body will cause profuse perspiration in five or ten minutes. Experiments by Pariset[2] with different kinds of thermometers show that thermometers exposed to radiant heat in the open air register very differently (a difference of 31° C.), according to whether the mercury bulb is a dull black or is of the usual polished glass. Even after fifteen minutes in a closed electric-light bath the two thermometers showed a difference of 9° C. (about 17° F.). It is essential that the temperature the patient is exposed to should be known and that the thermometer bulb should be blackened and should be exposed to the direct rays of the light at the same distance as the patient. Sweating may be produced by dark heat, but it requires a higher temperature and lacks the other effects produced by the penetration of radiant heat from a luminous source. It is not always necessary or desirable to have the electric-light bath closed up practically air-tight. It is sometimes pleasanter to the patient to have the light bath ventilated so that the patient is not in as hot an air bath as in the other case. To make this equally effective the light should be concentrated upon the patient and not wasted in heating the walls of the cabinet and the air contained therein.

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[1] Münch. Med. Woch., Jan. 16, 1906.

[2] C. R. de la Soc. de Biol., July 5, 1907.

An incandescent lamp with a long straight filament placed along the focus of a parabolic mirror (Fig. 422) yields parallel, not divergent, rays, which are directed toward the nearest surface of the body. All the light from a sufficient number of such lamps distributed uniformly over the surface of the body will produce the effects of light and radiant heat without the disagreeable effects of a hot-air bath.

The *temperature of the air* in the ordinary closed electric-light bath-cabinet is about 80° C. or 177° F.

The concentrated electric-light bath with ventilation causes perspiration to begin at a temperature of 77° F., and the maximum temperature of the air need not be over 112° F. A thermometer with a blackened bulb placed at the surface of the body and directly exposed to the rays of light and heat would register a considerably higher temperature, probably about 177° F.

Treatment by Concentrated Incandescent Electric Light.—Five hundred candle-power applied locally for about fifteen minutes is very effective in sciatica, lumbago, dyspepsia, colitis, pruritus vulvæ, rheumatoid arthritis, and cases upon the border-line between gout and neuritis. Some of the latter have finger-joints which are red and shiny and swollen and exquisitely tender. The application should be strong enough to redden the skin and cause the patient to move about to prevent overheating, but not strong enough to blister. Static electricity is a valuable adjunct in the treatment of these conditions.

Treatment by Red Light.—This is effective in smallpox, where it prevents pitting, and in scarlet fever, measles, erysipelas, and noma. It is ordinarily applied by keeping the patient in a room where only red light is admitted. There seems to be reason to think that the same results would not be obtained in complete darkness, that they are not due alone to the exclusion of the other colors, but that the red light has a specific effect upon the skin and renders it resistant to bacterial and other morbific agents.

The cure of recurrent sunburn by wearing a red veil,[1] and of eczema by sunlight, while the affected parts are covered by red cloth, are along the same lines. Freckles, seborrheic eczema, and rosacea seborrhœica have been treated by ointments containing a red pigment (Unna).

Blue-light Anesthesia.—The claim is made that blue light exerts a calmative and sedative influence and produces a sense of well-being, and that fixation of the eyes upon this light for a few seconds produces insensibility of the face. This is said to permit of the painless performance of minor operations, particularly the extraction of teeth.[2]

The patient's face is covered with a light blue veil; and there is a 16-candle-power incandescent electric-light bulb with a reflector at a distance of about 7 inches. The patient looks steadily at this for two or three minutes and at the end of that time is usually found in a dazed condition, with dilated pupils. Dr. Redard, of Geneva, developed this method for the painless extraction of teeth, and finds it successful in two-thirds of the cases. He and others who have used it successfully think the effect is a direct one upon the nervous system and not an example of hypnotism. The anesthesia is limited to the cranial nerves.

Blue-light Treatment.—Blue spectacles have long been used for the protection of normal eyes from the excessive sunlight at the seashore

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[1] Veiel, Vierteljahrsch. f. Dermatologie, 1887, p. 1114.

[2] Redard and Cavalié, Gazette Sciences medicale de Bordeaux, No. 38.

and for the protection at all times of eyes rendered sensitive by some disease. Smoked glasses seem to do equally well and it seems probable that the effect is due to the obstruction of a large proportion of the light, including practically all the ultraviolet rays rather than to the particular color of the glass.

The effect of blue glass windows upon the growth of plants and the health of persons in rooms thus illuminated were studied some years ago, but the method has been abandoned.

The Minin Lamp.—This is an incandescent lamp with a blue glass bulb and a reflector. Its effect is almost exclusively due to heat and is favorable in joint injuries and inflammations, and in eczema, superficial dermatoses, neuralgia, and rheumatism.

Kaiser's method of blue-light therapy[1] employs a carbon arc lamp actuated by a direct current of 15 amperes and 110 volts, with a parabolic reflector and a screen of strips of blue glass or a screen made of a glass-walled cell full of water in which methylene-blue and a little alum are dissolved. The latter makes the best screen because it arrests most of the heat rays. The patient is at the focus of the rays about 2 meters (6 feet) from the lamp. Good results are reported in tuberculosis of the joints and of the skin (lupus).

Blue-light with moderate heat has been used by the author in the treatment of pain and swelling of the face from irritation of the nerve leading to a tooth. Such a condition may occur after a crown is applied, and if it is simply from mechanic and chemic irritation without infection the author has seen it subside under this treatment. The lamp employed was a 32-candle-power incandescent blue glass bulb with a parabolic reflector. The face was protected by cardboard with a hole 3 inches in diameter which exposed the swollen cheek. The rays were not brought to a sharp focus, but concentrated upon the area, and the heat was entirely endurable, but still sufficient to redden the skin. Only one application was made, lasting ten minutes. The case did not progress beyond the stage at which the light treatment was applied, and in a short time the irritation subsided without having to remove the gold crown. How much the light treatment had to do with securing this result is a matter which the dentist (Dr. Gillett) is unable to decide. The patient herself did not think the light had produced much effect.

Blue-light Baths.—General baths of blue light at a temperature of from 104° to 122° F. and lasting for twenty or twenty-five minutes may be given every day at first and later every two or three days and each light bath may be followed by a bath in tepid water. They have a sedative and analgesic effect in such cases as neuralgia and rheumatism.

Local baths of blue light in the open air, not a cabinet, have been found very effective in different cases of neuralgia. Albert-Weil[2] reports the cure of a case of severe intercostal neuralgia of two months' duration by fifteen treatments lasting ten minutes each; and in a case of sciatica, in which other means had failed, blue-light baths effected a cure in fifteen days. The apparatus required is a 32-candle-power blue glass incandescent lamp with a large parabolic reflector.

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[1] Wiener klin. Rundschau, 1906, No. 4.

[2] Jour. de Physiotherapie, Sept. 15, 1905.

EXAMPLES OF THE THERAPEUTIC USE OF ELECTRIC ARC LIGHT

Ultraviolet light has been used in the treatment of ulceration of the cornea and of conjunctivitis, and in treating *x*-ray dermatitis.

The Ultraviolet Ray in Locomotor Ataxia.—Liebermann has reported beneficial effects from the ultraviolet ray applied alternately to the cervical, lumbar, and the sacral regions. Improvement took place in the pain and the coördination.

Its Use in Lupus.—This is extremely important and is described on page 601.

Electric-light baths with either incandescent or arc lamps are among the best means of treating rheumatism and gout and a variety of cardiovascular affections.

Angina Pectoris.—Fifteen patients treated by Jacobaeus[1] showed the following results: 4 very grave cases showed some improvement, but later succumbed to the progress of the disease; 3 old severe cases were improved and the severity of the attacks was reduced; in 3 milder cases the attacks of precordial pain disappeared entirely, and this was the case also in 3 moderately severe cases. That the effect was due to the treatment is shown by the recurrence of pain in 2 cases when the treatment was stopped and its disappearance when the treatment was resumed.

Hasselbach and Jacobaeus[2] have pursued the same line of treatment somewhat further. They use powerful carbon arc lamps in the baths and obtain a dermatitis which from repeated applications becomes a chronic hyperemia lasting perhaps as long as a year and may be accompanied by a lasting effect in relieving internal congestion and the like. Respiration exchanges are unaltered, but respirations become less frequent and deeper, inspiration being prolonged. A patient with cardiac distress breathes much more freely. Arterial pressure begins to diminish after the third treatment. Both the diastolic and the systolic pressures are reduced, but the difference between the two becomes greater than before. The pulse-rate is unaffected. Dilatation of the heart is usually reduced during a course of treatment.

Fifty cases of various neuroses treated in this way showed great improvement.

One hundred and thirty-one patients with chronic or organic heart-disease were treated. In some cases the valvular insufficiency was only moderated, but even then the sense of fulness and tension was reduced and so were the dyspnea and palpitation on exertion. Cardiac dilatation was usually reduced; 44 cases of true angina pectoris gave rapid and strikingly favorable results which were quite lasting.

Combined Electric-light Baths and Hydro-electric Baths in Obesity.—The electric-light bath is followed by a general warm water bath which is progressively cooled, while at the same time a sinusoidal current of 100 to 120 ma. is applied through it for twenty to thirty minutes; this is one of the most effective modes of treatment. Fatty degeneration of the heart is a contra-indication to this treatment.

Examples of the Use of the Mercury Vapor Lamp.—The author has employed the Cooper Hewitt lamp with benefit in a case of laryngeal and pulmonary tuberculosis. A lamp of 450 candle-power, to which is added the influence of a reflector back of it, is placed horizon-

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[1] Semaine Med., May 22, 1907.

[2] Second International Congress of Physiotherapie, Rome, Oct. 13, 1907.

tally in front of the bare chest at a distance of 5 or 6 inches from the skin. An exposure of ten minutes reddens the skin temporarily. The treatment was combined with the use of the x-ray and high-frequency currents and resulted in the healing of the ulcerated vocal cords and a marked increase in weight, appetite, and strength. Financial difficulties then caused the patient to discontinue the treatment and she died of pulmonary tuberculosis about a year later.

Nogier and Thevenot have shown by their experiments[1] that applied in this way the light from the Cooper Hewitt lamp does not kill or apparently influence bacteria with an exposure of seventy-five minutes. But in a more highly concentrated form the mercury vapor light has a bactericidal effect and may be used in the treatment of lupus (Kromayer).

As an electric-light bath the light from the Cooper Hewitt mercury vapor lamp produces a general tonic effect, improving the appetite and digestion and removing insomnia. Nogier has seen long-standing cases of amenorrhea become normal under the treatment. He obtained satisfactory results in cases of anemia and chlorosis by combining this treatment with general measures.

Locally, it has the usual analgesic effect of radiant heat combined with light, and relieves gouty and rheumatic and muscular pains.

Pelvic pains of various natures are often relieved by applying this or similar lights over the hypogastrium.

Nogier has shown by actual dynamometric measurement in 12 patients that there is an increase in muscular power.

Vacuum Bulbs of Pure Quartz.—These can be made up to about 2 inches in diameter by fusing quartz sand with scarcely any other admixture. They transmit the ultraviolet ray perfectly and mercury vapor lamps so constructed are very active physiologically.

The *uviol lamp* is practically the same as the Cooper Hewitt lamp, except that the tube is made of glass which is supposed to transmit high rates of vibration and hence more of the ultraviolet rays. The effect of the uviol lamp has not been fully tested, but it has been found to be very active superficially, and Pellizari has not found it to produce as deep an effect upon lupus as the Finsen lamp.

Diagnostic Uses of the Cooper Hewitt Light.—The normal face presents a strikingly unnatural appearance by this light which is devoid of red rays. Every red blood-vessel looks almost black and the lips are a dark purple. The skin of the chest and abdomen may be examined in cases of suspected syphilis before the eruption; the latter being visible by this light several days before it is perceptible by ordinary light. In the same way at a later stage the eruption may be found after it is no longer noticeable by ordinary light. The Cooper Hewitt mercury vapor lamp may also be used to watch for the earliest evidence of Röntgen dermatitis.

Therapeutic Uses of the Kromayer Lamp.—This light may be applied to the treatment of recent trachoma.

One end of a quartz rod is in close contact with the quartz tube of the lamp, and all the light passes to the other end of the rod and affects the tissues without any lateral diffusion. This is a successful method of treatment.

With the lamp at a distance of at least 4 inches from the skin, an application of five to fifteen minutes is effective in a wide range of skin

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[1] Second Congress of Physiotherapy, Rome, Oct. 13, 1907.

diseases. Alopecia areata, alopecia pityrodes, pityriasis rosea, superficial mycoses, pruritus, vitiligo, acne, furuncle, carbuncle, lupus erythematosus, folliculitis decalvans capitis, folliculitis barbæ, cutaneous tuberculosis, ulcers may be treated in this way.

With the lamp in close contact and the tissues blanched by compression or by adrenalin, but protected from excessive heat either by the water circulating in the lamp itself or by a blue screen of uviol glass to arrest the superficially acting chemic rays, the effect is a penetrating one, and the longer applications should only be made after considerable personal experience with the milder ones. The dosage for lupus vulgaris is fifteen to forty-five minutes; lupus erythematosus, one to thirty minutes; epithelioma, thirty to sixty minutes, lupus erythematosus, one to thirty minutes; epithelioma, thirty to sixty minutes; nevus vasculosus, thirty to sixty minutes; telangiectasis, five to thirty minutes; acne rosacea, five to thirty minutes; ulcers, five to thirty minutes.

A quartz mercury vapor lamp, suggested by *Bach and Nagelschmidt*, is intended for application at a distance of 20 inches or so for a reflex effect upon blood-pressure and for the treatment of a long list of skin diseases: lupus, chancroid, lipoma, nevus, alopecia areata, acne vulgaris and rosacea, eczema, frost-bites, intertrigo, erythrasma, chronic ulcers, psoriasis, eczema seborrhoica, falling of the hair, vitiligo. The dosage for a constitutional effect is three minutes front and back at a distance of 28 inches for the first treatment, gradually increased at subsequent treatments as the skin becomes tanned. Finally, the exposures may be as long as twenty minutes at a distance of 15 inches. The dosage in eczema is one minute at 16 inches, gradually increased at subsequent treatments to a maximum of five minutes at a distance of 8 inches. Acne, eczema, and other diseases of the face should receive at first one minute at 20 inches and gradually increased to a maximum of three minutes at the same distance. Closing the eyes protects them sufficiently.

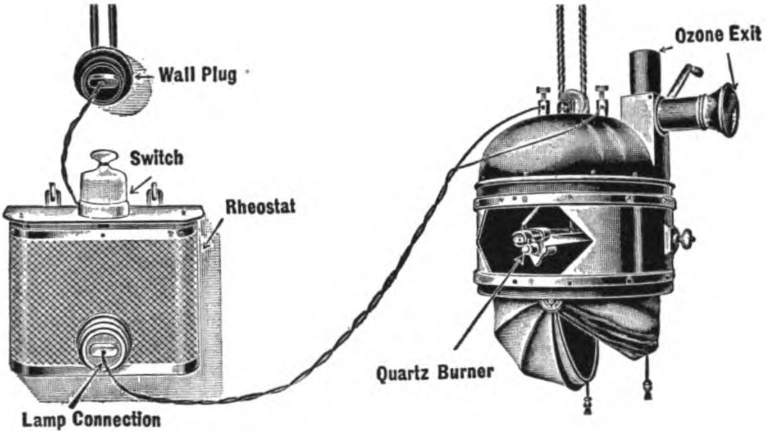

Fig. 423.—Miniature alpine sun (Hanovia Chemical and Manufacturing Co., Newark).

Many of the indications for electric-light treatment in medical gynecologic and surgical cases are met by this lamp.

Sunlight in the Treatment of Tuberculosis.—A host of observations show that exposure of the part to the direct rays of the sun produces benefit in tuberculosis of the bones and joints.

THE *X*-RAY

DISCOVERED by Röntgen, in Würzburg, April 30, 1895, the *x*-ray was something entirely new and not foreshadowed by anything else.

Röntgen was studying the Crookes tube and the cathode ray and had the tube so thoroughly covered with black cardboard that no visible light could escape into the darkened room. He noticed, none the less, that a sheet of paper coated with tungstate of calcium began to emit light. He had discovered the *x*-ray, a form of radiation which will pass through substances opaque to ordinary light and produce luminous effects upon certain objects beyond.

It is a form of motion similar to light, but with some trillions of vibrations a second and a wave-length as short, sometimes, as $\frac{1}{2}$ cm. It penetrates solid bodies opaque to light waves and causes brilliant fluorescence in certain chemic substances beyond.

The *x*-ray itself is invisible. Our perception of it is due to the luminosity of fluorescent substances which it shines upon.

Differences in the Penetrating Power of Ordinary Light of Different Colors.—Even weak blue light will go through a blue solution and illuminate objects beyond, while the strongest blue light will be stopped by a solution of bichromate of potash. The reverse is true of yellow light.

The ruby colored glass which forms the window of a photographic dark-room transmits the red rays of ordinary light in sufficient abundance to enable one to see objects distinctly, but if a blue light were used outside of the dark-room practically none of it would penetrate the ruby glass and the interior of the dark-room would be in complete obscurity. There are many other examples of substances which are transparent to ordinary light vibrations of a certain wave length and opaque to others.

Many substances which are not transparent, still are translucent. The shadow of the hand is readily seen through a piece of porcelain or a sheet of white paper. Neither of these substances would serve as a wrapper for a sensitized photographic plate. The light goes right through them and would fog the plates. Black paper, however, absorbs all the rays of ordinary light and serves to protect photographic plates from ordinary light. Transparency to ordinary light is like color, in that it depends upon the arrangement of the molecules of the substance rather than upon the ultimate chemic or atomic composition. Coal is opaque, while the diamond, consisting of about equally pure carbon, is perfectly transparent to ordinary light. A transparent solution of albumin shaken up with a transparent oil will form an opaque emulsion. Specific gravity plays little or no part in regard to transparency to ordinary light. Cork and black paper are opaque, while glass, which is very much heavier, is transparent.

It is not strange then that certain substances which are opaque to ordinary light should be transparent to the *x*-ray, which has quite a different rate of vibration.

Differences Between the x-Ray and Ordinary Light.—The x-ray differs in several ways from ordinary light in regard to its penetrating power. In the first place it is not influenced by molecular arrangement, but probably depends entirely upon the atomic composition of the substance, and, generally the greater the specific gravity the more opaque the substance is to the x-ray. Books and aluminum and vulcanized hard rubber are very transparent. Glass is transparent, but less so if it contains lead. The human hand, water, and bisulphate of carbon are transparent. Copper, silver, lead, gold, and platinum are transparent if not in too thick plates; 0.2 mm. of platinum is transparent. Silver and copper may be decidedly thicker; 1.5 mm. of lead is quite opaque. The salts of the different metals give very similar results, whether solid or in solution.

Absorption of x-Rays by the Air.—Air absorbs about 1 per cent. of the x-ray per decimeter (4 inches). Eve and Day[1] find that rays from a very hard x-ray tube show an absorption of about 0.00025 for each centimeter of air, a medium tube 0.0004, and a very soft tube from 0.001 to 0.0018. These figures were true at distances of from 4 to 40 meters. The rays reaching beyond the latter distance showed a lessened rate of absorption.

The opacity is not in direct relation with the density of the objects. If it were so, a sheet of aluminum 6 inches square and thick enough to be as opaque as a sheet of platinum 6 inches square ought to have the same weight. This is very far from being the case. In one series of experiments by Röntgen sheets of platinum, zinc, lead, and aluminum were rolled until they appeared to be of almost equal transparency. The following table gives the thickness in millimeters of the thicknesses relative to the platinum and density:

	Thickness.	Relative thickness.	Density.
Pt	0.018	1	21.5
Pb	0.05	3	11.3
Zn	0.10	6	7.1
Al	3.5	200	2.6

In this experiment a sheet of aluminum would have to be 200 times as thick as a sheet of platinum in order to have the same opacity, and as its density is about one-eighth that of platinum, the sheet of aluminum would weigh twenty-five times as much as one of platinum equally opaque to the x-rays.

The relation between density and opacity to the x-ray varies under different conditions of the x-ray tube. When the tube is giving out mostly hard or highly penetrating rays a piece of aluminum 12 mm. thick has the same opacity as a sheet of silver 0.11 mm. thick; while with a very low degree of vacuum in the x-ray tube 1 mm. of aluminum has the same opacity as 0.11 mm. of silver. This is the basic principle of the Benoist radiochromometer, an instrument for measuring the quality of the x-ray. Color has no influence upon transparency to the x-ray, and neither has the fact that the substance is opaque or transparent to ordinary light. Glass is much less transparent to the x-ray than black paper, wood, or aluminum.

Lenard's Law.—Different substances impinged upon by x-rays of the same wave-length absorb them equally for equal weights.

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[1] Phil. Mag., 23, 1912, 683.

X-rays are not refracted by glass prisms or by water or carbon bisulphite. Powdered substances are quite as transparent to the *x*-ray as are solid bodies of equal mass. The *x*-ray cannot be concentrated by lenses. No appreciable regular reflection occurs.

Rood's observations in regard to the reflection of *x*-rays[1] seemed to indicate that $\frac{1}{1000}$ of the *x*-ray was reflected from a metallic surface which it strikes at an angle of 45 degrees. In the light of our present knowledge it seems probable that this small fraction of *x*-ray found in a region which it seemingly could only reach by reflection gets there either by secondary radiation or by direct penetration through the intervening objects.

Ordinary light may be made up of a mixture of different colors, but if separated by a prism each such colored beam of light is produced by a succession of uniform waves.

The reflection and refraction of light are supposed to depend upon this property of regularity of vibration which is lacking in *x*-rays to a very great extent. A stone dropped into water starts a wave or elevation of the surface of the water which forms a circle of constantly increasing size, and if this were only followed by other waves when other pebbles of various sizes were thrown into the water with different speeds the resulting waves would be analogous to those of the *x*-ray. Each wave of the *x*-ray requires a separate and distinct impulse and may have a different velocity from the one preceding or following it.

Another reason why *x*-rays are not ordinarily reflected is that the vibrations are so much smaller than those of light that an ordinary mirror is as coarse to them as the surface of this paper is to ordinary light, which it partly transmits, partly absorbs, and partly diffuses. Diffusion in the case of the *x*-ray is by secondary rays. It has recently been observed that the *x*-ray is reflected to some extent from the cleavage planes of certain crystals.

The intensity of the illumination of the fluoroscopic screen varies inversely with the square of the distance. The *x*-ray is not deflected even by a very strong magnet.

Sir George Stokes' Theory of the Nature of the *x*-Ray.—The rays are due to a succession of independent pulsations in the luminiferous ether starting from the points of impact of the cathode particles upon the anticathode. These are not continuous vibrations like those of ordinary light; they are isolated and extremely short. They are transverse like those of light and have the same velocity. According to Sir Joseph Thomson these pulsations are electromagnetic waves.

Corpuscular Theory of the *x*-Ray.—It is believed by Bragg, Porter, and others that the *x*-ray consists of material particles traveling at a very high rate of speed. Most observers, however, believe that it consists of vibrations of the luminiferous ether. It is interesting to note in this connection that ordinary light is deviated by gravitation. The light from a star passing near the sun deviates about 0.8 second.

PROPERTIES OF THE RÖNTGEN RAY

It produces an image upon a photographic plate in a container opaque to ordinary light and produces effects upon living animal tissues. It causes the air through which it passes to become a conductor of electricity, and in this way discharges a positively or negatively charged body.

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[1] Science, March 27, 1896.

It is itself invisible and does not produce the sensations of heat, light, or sound. When it encounters a solid substance it gives rise to secondary x-rays and to cathode rays, and while it does not itself carry an electric charge, one is secondarily produced in bodies exposed to it. This is due to the ionization of the air, as explained later. The x-ray is not subject to ordinary refraction or reflection.

Polarization of x-Rays.—C. G. Barkla has shown that primary x-rays and heterogenous secondary x-rays are partially polarized for certain directions of propagation.

Some of the x-rays from the anticathode of an ordinary x-ray tube are proved to be polarized by an experiment which shows that the secondary rays arising from the impact of the primary rays are of a different quantity and quality, according to whether they lie in the plane of the cathode stream or at a right angle to it. The entirely polarized rays from an ordinary x-ray tube have the property of generating especially rapid cathode rays. The non-polarized part differs only in degree about this. An aluminum screen increases the polarization slightly.

As far as our present knowledge goes the x-ray travels in perfectly straight lines, but on striking any solid substance a portion of the rays is absorbed, another portion goes straight through, and a third portion, or perhaps an effect of the other two, causes a diffusion of x-rays and cathode rays in every direction, so that everything in the x-ray room is affected by it. The only way to prevent a photographic plate in the x-ray room from being fogged, for instance, is to keep it in a closed box of thick metal. The x-ray consists of many different wave-lengths and these have different degrees of penetration. Different substances present more or less resistance to the passage of the x-ray and this absorption is very closely related to the atomic weight of the substance. The greater the atomic weight the greater the resistance to the passage of the x-ray, and this is true regardless of the transparency or opacity of the substance as regards ordinary light. Wood is very transparent to the x-ray, and so is aluminum, while glass is much less transparent and is more or less opaque in any thickness greater than $\frac{1}{8}$ inch. The same difference in the amount of absorption is shown by the different tissues of the body. The lungs are almost perfectly transparent, and the superficial fascia with its layer of fat, the muscles and solid organs, the bones and the teeth absorb the x-ray to a greater degree in the order given. The different degrees of absorption cause the x-ray which has passed through any part of the body to produce a visible image upon a fluorescent screen or a photographic plate. We shall see further on that an x-ray picture is a chart of densities of the different tissues traversed, and that next to safety the desiderata in radiography and fluoroscopy are great intensity of radiance and a quality of x-ray, which shows the greatest difference in the degree of absorption in passing through different tissues.

Very soft x-rays are produced by an x-ray tube which is so constructed as to be excited by a potential of only 900 volts. W. Seitz[1] finds that different gases absorb these rays in different proportions, but not in any direct proportion to their atomic weight. For instance, for rays produced by 1400 volts oxygen is very opaque and vapor of sulphur very transparent.

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[1] Phys. Zeit., 13, 1912, 476.

The secondary rays arising when the x-ray strikes any solid object, or even when it passes through the air, show evidences of being polarizable. Haga[1] finds that under appropriate conditions the secondary rays are five times as strong in one plane as in another at right angles to it. This tends to the conclusion that the x-ray is due to transverse vibrations in the luminiferous ether.

Characteristic Homogeneous Röntgen Rays.—These form part of the x-radiation from the anticathode of a Crookes' tube and have a uniform wave-length which is dependent upon the specific gravity of the anti-cathode. The heavier metals produce the more penetrating characteristic Röntgen rays.

Influence of Material of Anticathode Upon Character of Röntgen Rays.—The lower the specific gravity, the more absorbable are the characteristic homogeneous x-rays. There are always heterogeneous x-rays in addition which are not affected by the nature of the anticathode except as to quantity, being less abundant with a low specific gravity.

Secondary x-Rays and Homogeneous x-Rays.—A metal impinged upon by x-rays gives out several kinds of x-rays: Two kinds of x-rays, one heterogeneous of the same wave-lengths as the primary x-rays, and one homogeneous, characteristic of the metal impinged upon and only excited by primary x-rays of more rapid vibrations; also there are cathode particles.

They do not continue to be emitted for even $\frac{1}{3000}$ second after the exposure ceases.

The characteristic homogeneous secondary x-rays are more abundantly generated by impact upon substances of high atomic weight and are independent of whether it is a pure element or a compound.

J. C. Chapman[2] has shown that the same characteristic homogeneous secondary x-rays are produced when the substance is in gaseous form.

The impact of homogeneous x-rays produces homogeneous and heterogeneous secondary x-rays, and also secondary cathodic corpuscular rays.

When x-rays are sufficiently hard to produce a secondary homogeneous characteristic radiation in one of the elements present in a gas, there is always an increase in the emission of secondary corpuscular rays in the absorbent power of the gas for the rays in question and in the ionization of the gas produced by them.[3] It is uncertain whether the major part of the ionization of a gas is produced by the x-rays themselves or by the secondary corpuscular rays. Barkla and Simons,[4] conclude from their experiments that it is chiefly due to the x-rays.

Production of Characteristic x-Rays.[5]—The cathode (C) is plane. The cathode rays are about parallel and pass through a perforation in the anode into a space Z, where they are deviated to different extents by a magnetic field. Z is a brass cylinder around which turns of insulated copper wire carry a current in one fixed direction, producing the magnetic field indicated by M–N. The voltage is varied until the cathode rays, which will excite its characteristic rays, reach V, an anticathode of the material to be tested. Through the window (W) of aluminum pass practically exclusively the characteristic x-rays. He finds the voltages required are for:

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[1] Proceedings of Academy of Sciences, Amsterdam, August, 1906.

[2] Phil. Magazine, 21, 1911, p. 446.

[3] Barkla, Le Radium, 7, 1910, 115; 8, 1911, 28, and 9, 1912, 61.

[4] Phil. Magazine, 23, 1912, 317.

[5] R. Widdington, Cambridge University, Le Radium, 8, 1911, p. 286.

Aluminum	2,600 volts.
Iron	9,200 " .
Copper	10,000 " .

representing velocities of the cathode particles 2.8 x 10^9 cm. per second for aluminum, 5.70 x 10^9 for iron, and 6.18 x 10^9 for copper.

Characteristic Absorption of Heterogeneous *x*-Rays by Different Materials.—Charles A. Sadler and A. J. Steven[1] show that with an aluminum anticathode, a window of aluminum, 0.00367 cm. thick, arrests the characteristic homogeneous *x*-rays while transmitting the heterogeneous *x*-rays which may prove to have a certain penetration. Now, increasing the thickness of the aluminum window, they find that the emergent heterogeneous rays have become softer, not more penetrating by the increased thickness of the aluminum. Using screens of different materials they find that heterogeneous rays which have passed through iron have become more absorbable or softer for aluminum than the heterogeneous rays from the same tube without the interposition of the iron screen.

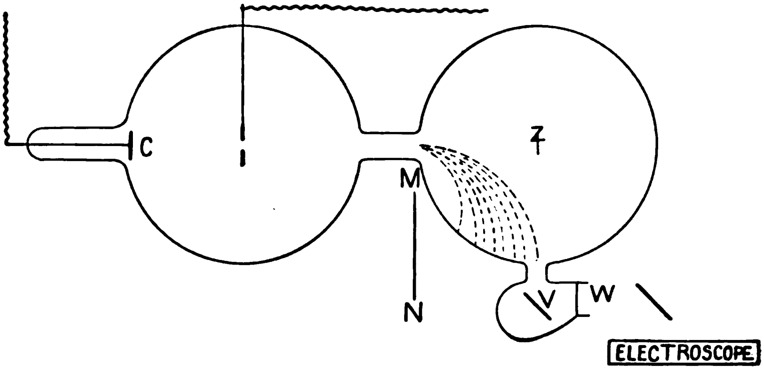

Fig. 424.—Separation of *x*-rays into different wave-lengths by a magnetic field, M to N, and production of characteristic homogeneous secondary *x*-rays at the accessory anticathode, V. W is an aluminum window beyond which an electroscope detects these rays.

The theory is that substances absorb especially the *x*-rays, which would form their characteristic homogeneous radiation if they were used as anticathodes.

The characteristic *x*-rays from iron are highly penetrating to aluminum, and if these are especially absorbed the average penetration to aluminum is reduced. An aluminum screen first increases the penetration to an iron screen beyond.

This does not mean that more *x*-ray gets through the iron screen than if the aluminum screen were not there also. It means that a greater percentage of rays which reach the iron screen get through it.

Other Ways of Photographing Without Light.—*Electrophotography.*—An ordinary photographic plate wrapped in black paper is laid upon a small sheet of metal about the same size. The latter is connected with the negative pole of a small spark coil (1 inch). The film side is uppermost and a coin is laid on top of the envelope. Over the coin another sheet of metal is laid which is connected to the positive terminal. A single spark is passed across the spark-gap. Upon developing the plate

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[1] Phil. Magazine, 21, 1911, 659.

a perfect image of the coin will be obtained. Around the periphery of the coin a ring or border of minute sparks will be seen.

Bi-electrographs.—A coin is placed between two dry plates with the same result, the best results being obtained when the plates are bare in a dark room.

Magnetographs.—The plate is wrapped in light proof paper with the coin on top, laid directly on the film side of the plate. A piece of cardboard is laid upon the pole terminals of a powerful horseshoe or electromagnet; the plate facing the magnet is laid upon it. The armature is then gently presented to the glass side of the plate and allowed to remain as attracted by the magnet for a few minutes—five to ten. The plate is developed and the negative obtained will show a shadow of the coin. The result is due to magnetism, not to x-ray.

Thermographs.—The plate is placed in water for a very short time; the coin is then laid upon it and pressed somewhat. The coin is to have a different temperature, either hotter or colder than the film. Copper coins should be used, as silver will not give the effect. The developer is then poured into a tray with the coin still in position. The coin is then removed and the development is continued. After ten or sixteen minutes' development or even half an hour, we find an image of the coin there.

Ionization.—The x-ray ionizes a gas through which it passes, and therefore causes insulated positively or negatively charged bodies to lose their electric charge. Air through which the x-ray has passed remains ionized for some time, and if aspirated through a tube this ionized air will discharge an electrified body which has itself never been exposed to the x-ray. A plug of cotton wool or several layers of very fine wire screen will remove the ionization from air passed through it. Tossing about a large object, whether electrified or not, in ionized air quickly deprives the air of this property. It is gradually lost under any circumstances.

X-rays ionize di-electric liquids as well as gases.

A pencil of homogeneous x-rays from copper or silver passes through a window of aluminum into the interior of a cylindric condenser, which metal gives out hardly any secondary rays under the influence of rays characteristic of copper or silver.

W. Bragg[1] has made certain observations upon the β-rays, or secondary cathode particles excited by the impact of x-rays upon solid substances, and has found that the ionization of the surrounding gas is no more than would be accounted for by these secondary cathode rays. He considers it doubtful whether the x-ray itself ionizes gases directly.

Small ions are such as are produced by the passage of the x-ray or of the Becquerel rays through the air. They move through a distance of about 1 cm. *Large ions*, discovered by Langevin, are 50 times more numerous in the normal atmosphere, but their mobility is about 2000 times less.

An electrically charged body with a solid non-conductor like paraffin, which is transparent to the x-ray, interposed, loses its charge when exposed to the ray, but this does not take place if there is a complete outer metallic envelope connected with the earth. The discharging effect is due to contact with ionized air.

The x-ray cannot be concentrated by lenses. An x-ray picture is purely a permanent shadow, hence the name *skiagraph*.

[1] Phys. Zeitschr., 12, 1911, 1184.

THE PRODUCTION OF THE X-RAY

A glass bulb has two wires entering and fused into it and is exhausted to the proper degree of vacuum, about $\frac{1}{1,000,000}$ atmosphere, and the wires are made the positive and negative terminals of an electric circuit. When a current of very high potential is passed through such a tube a stream of molecules is repelled from every part of the surface of the cathode or negative terminal, and normally, *i. e.*, perpendicularly, to this surface. This cathode stream on striking any solid substance, like the glass wall of the tube, gives rise to the form of motion called the x-ray. The greatest improvement in the construction of x-ray tubes since the original discovery was in giving the cathode a concave surface and focusing the cathode stream upon a platinum disk called the target or anticathode. This causes the x-ray to radiate from a very small point and permits of much heavier currents being used than was possible when the cathode stream was directed against the more easily fused glass wall of the tube. There has consequently been a wonderful gain in intensity and clearness of definition.

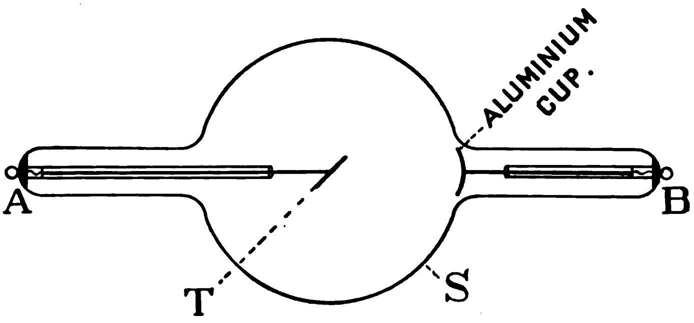

Fig. 425.—Simple form of x-ray tube: *T*, Target or anticathode.

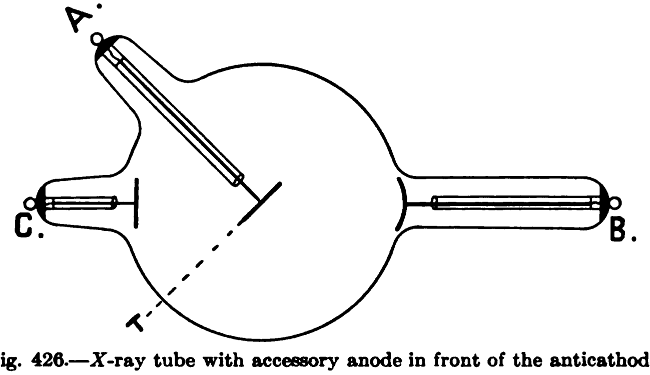

Fig. 426.—*X*-ray tube with accessory anode in front of the anticathode.

Directions for Successfully Operating an x-Ray Tube Excited by Either a Static Machine or an x-Ray Coil.—Before proceeding to describe the methods of using x-ray tubes, it is first essential that the operator should know the names of the different parts of a tube. Fig. 425 illustrates the most simple form of x-ray tube used at the present time. *T* represents the target, or anticathode, which may be of any shape, but which will almost always be placed near the center of the bulb, and at an angle of 45 degrees to the long axis of the tube. *A* is the external connection of the anticathode; *B* is the external connection of the aluminum cup or cathode. The aluminum cup and the target are common to all ordinary x-ray tubes, and are practically always placed in the above-described positions.

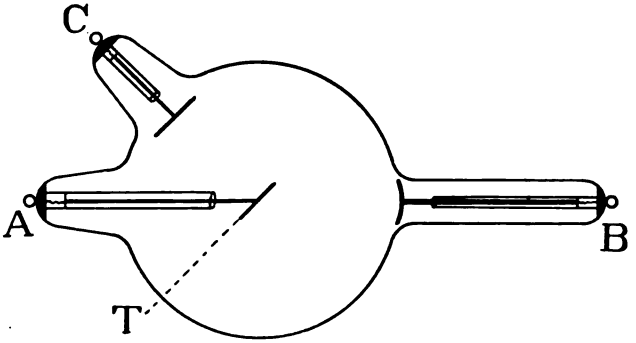

Fig. 427.—*X*-ray tube with accessory anode behind the anticathode.

The next most common type of tube is shown by Fig. 426. As you will notice, the target and aluminum cup are in the same relative positions as in Fig. 425. There is, however, an additional connection (*C*), having a flat aluminum disk inside of the main bulb. Sometimes it is a flat disk as shown, and again, it is simply a straight aluminum rod which may be sharp-pointed. In a recent Greene and Bauer tube the accessory anode consists of a sheet-iron cylinder which is supposed to trap certain deleterious gases, but in the author's hands this has not shown any particular difference. Instead of placing this disk in the position shown in Fig. 426, it may be placed as shown in Fig. 427, the difference being simply that the flat disk is placed back of the target instead of above it. It is so placed as a matter of convenience in manufacture, but is less desirable in case there is any inverse discharge.

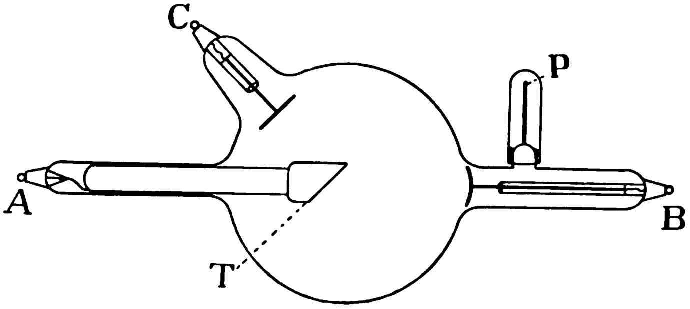

Fig. 428.—*X*-ray tube in which the resistance may be adjusted by the osmo regulator.

The next type of tube, illustrated by Fig. 428, is one in which the resistance of the tube can be regulated. *P* represents a short piece of palladium or platinum tubing, which is sealed into the x-ray tube and has the outer end soldered. When the palladium or platinum tubing is heated to a bright red, it allows gas to pass through it into the x-ray tube, and in this manner renders the inside of the bulb a better conductor than before heating. The particular caution in using this style of regulator is to pay attention to the color of the metal. Do not bring it to a white heat and do not apply the heat too close to the glass. If the metal is overheated, the tube becomes what is known as a leaker, and can only be remedied by putting in a new regulator. If the heat is applied too close to the glass it is very liable to crack it.

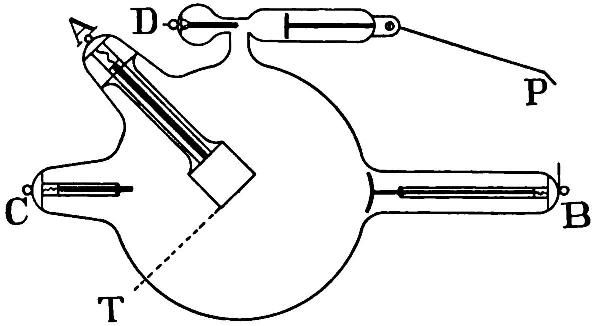

Fig. 429.—Self-regulating tube.

Fig. 429 illustrates a self-regulating tube. When a spark passes between the brass pointer *P* (patented by Queen and Company) and the negative connection *B* it causes a gas to be liberated from the mica disks, and in this manner lowers the resistance of the tube. If a connection from the positive pole of the apparatus is made to the terminal *D*, it causes the fine metal wire which is wound around a small glass rod to

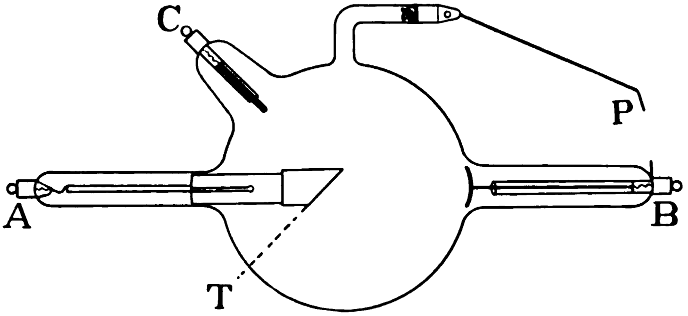

Fig. 430.—Another type of self-regulating tube.

absorb whatever free gas may be in the bulb, and in this manner increases the resistance of the tube.

Fig. 430 illustrates another type of self-regulating tube. This acts in the same manner as the one above described, excepting that it does not have any device for increasing the resistance of the tube.

A great many tubes are being put on the market, and very often the dealer neglects to send directions with the tube, but if you will always remember to connect the target with the positive pole of your apparatus, and the aluminum cup with the negative pole of your apparatus, you are certain to have it connected properly, and whatever other connections may be on the tube are for regulating its resistance in some manner.

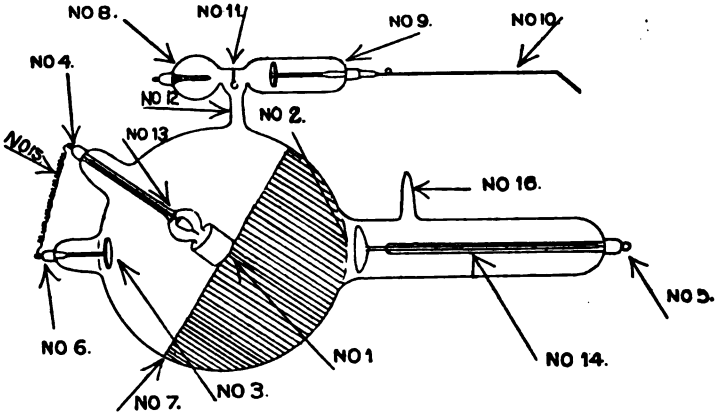

Fig. 431.—Chart of an *x*-ray tube: 1, Anticathode or anode surface; 2, cathode surface; 3, anode or accessory anode surface; 4, sealing-in point and cap of anticathode; 5, sealing-in point and cap of cathode; 6, sealing-in point and cap of anode; 7, hemisphere of *x*-ray; 8, heightening device on regulator or auxiliary anticathode; 9, lowering device on regulator or auxiliary cathode; 10, movable swivel on regulator; 11, wall between universal regulating device; 12, connection between main bulb to regulating device; 13, glass rod back of anticathode; 14, glass rod back of cathode; 15, wire between anticathode and anode; 16, exhaust tip.

Fig. 431 depicts the different parts of a Friedlander or a Müller, No. 13, heavy target *x*-ray tube.

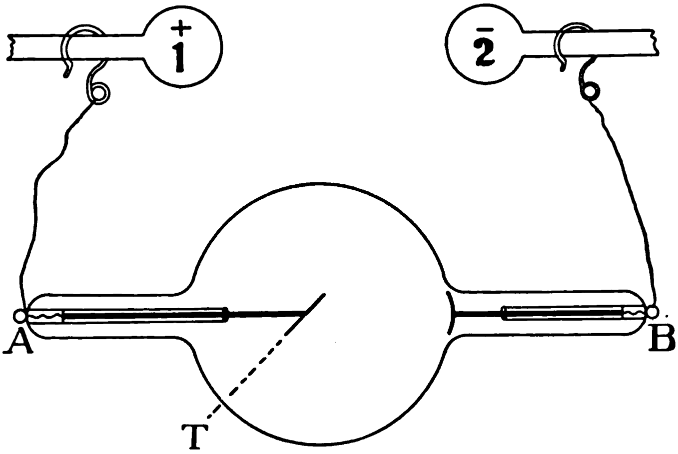

Fig. 432.—*X*-ray tube connected with the sliding rods of an electric machine.

The first thing to know about a tube is to have a clear understanding as to what is meant by a soft or low tube, a medium and a high or hard tube, and in connection with this Fig. 432 shows an *x*-ray tube connected directly to the sliding rods of a static machine or the secondary terminals of an *x*-ray coil. Assume that it is connected with the terminals of a static machine whose discharging rods 1 and 2 are in contact, then upon slowly separating them a spark will appear which ceases when they are separated ½ inch, and the tube lights up. This would be termed a soft or low tube, having a parallel spark-gap of ½ inch. By the parallel spark-gap is meant that having a tube connected as per illustration, and 1 and 2 in contact, then the distance which it is necessary to separate them to stop the spark from passing between them is known as the parallel spark-gap. A parallel spark from ½ inch to 1½ inches on the static machine would mean a medium tube; from 1½ to 2½ inches, a high tube, and a tube should not be used having a parallel spark-gap of more than 4 inches on the static machine. On a coil a parallel spark-gap of 3 inches gives about the same ray as the ½-inch parallel spark-gap on the static machine. A 5-inch parallel spark-gap about the same as the 1½-inch on the static machine, and an 8-inch parallel spark-gap on the coil the same as the 3-inch on the static. A tube that has a parallel spark-gap of 9 inches, should have the adjustor so that it just stops the spark from appearing between the terminals of the coil. When a tube has a parallel spark-gap of less than ½ inch on a static machine, then by means of what is known as *spark-gap* or *light-regulator*, as shown in Fig. 405, a very much better ray can be obtained from the tube by separating 3 and 4, so that a spark appears between them. If the tube is very low, having a parallel spark-gap about ⅛ inch, then it may be necessary to separate 3 and 4 on each side from 1 to 2 inches. When this is the case, a multiple spark-gap, as shown in Fig. 406, gives a more steady ray. This is due to the fact that the row of brass balls keeps the spark in line, and it does not tend to fly off, as when a single spark-gap of the same total length and resistance is used. The action of the spark-gap in connection with the static machine is to allow it to generate more current. A static machine on short circuit or a very low resistance, such as is the case when an

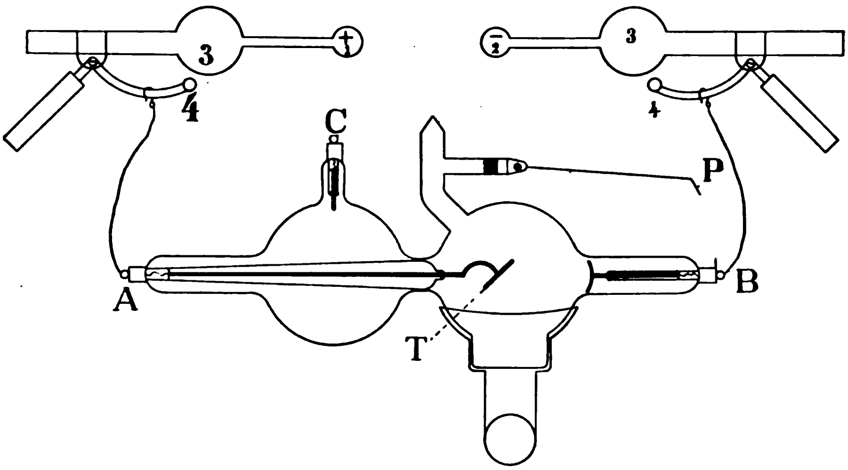

Fig. 433.—Spark-gaps (3 to 4) for *x*-ray use of the static machine.

x-ray tube having a parallel spark-gap of $\frac{1}{8}$ inch is used, will generate a comparatively small amount of current, whereas, when a resistance is introduced into the circuit, it generates more current, and, in fact, the more resistance introduced in the circuit the more current the machine will generate up to its capacity. Aside from the short parallel spark-gap, another indication that a tube is low or soft is the appearance of a blue stream between the target and the aluminum cup (Fig. 435). The majority of the x-rays are generated on the target at the point at which this blue stream strikes, and this blue stream is called the cathode stream. Prof. S. P. Thompson has demonstrated the fact that the x-rays are given off in equal numbers in all directions from the anterior surface of the target, and not a maximum number at right angles to the center of the target. *Caution:* When a tube is to be used do not separate the secondary terminals of the apparatus more than 1 inch beyond the parallel spark-gap of the tube; and if it is used on a static machine, and has a parallel spark-gap of more than 3 inches, then use the regulator just sufficiently to obtain a 3-inch parallel spark-gap, and if on a coil an 8- or 9-inch parallel spark-gap at the most. The shorter the parallel spark the less will be the penetrating quality of the rays.

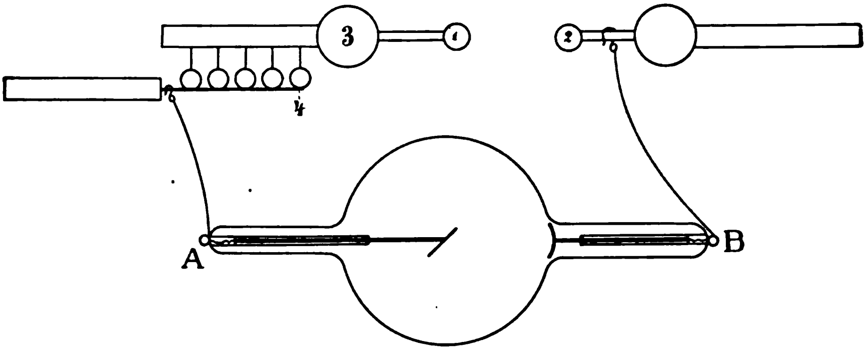

Fig. 434.—Multiple spark-gap.

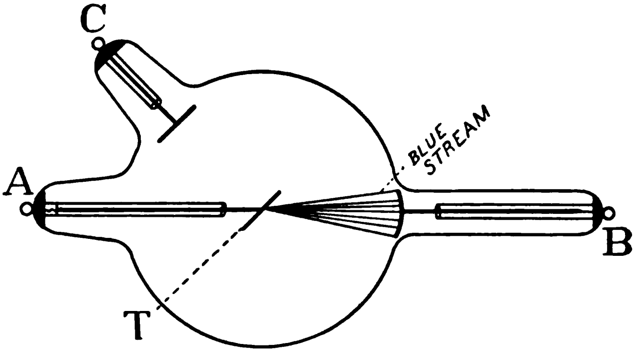

Fig. 435.—Visible cathode stream in an x-ray tube with too low a vacuum.

When a tube of the type shown in Fig. 435 is connected as follows: *C* to the positive terminal, *B* to the negative terminal, then if this is a *medium* tube, these connections will give the least parallel spark-gap of this particular tube. If the positive connection is made on the terminal *A*, the parallel spark-gap of the tube will be *somewhat* higher, and if *C* and *A* are connected and then connected to the positive terminal, this will give the *highest* parallel spark-gap of this particular tube, and it does not make any difference whether the positive connection is then attached to *C* or *A*. This difference applies to tubes which, when connected as last described, have a parallel spark-gap of 1 inch or less on a static machine and 5 inches or less on an *x*-ray coil.

The Piffard safety *x*-ray tube (Fig. 436) was designed for the purpose of doing away with the enclosing shields which have been made for *x*-ray tubes. This tube, which consists of two 4-inch lead glass bulbs (two bulbs being used, as it was found impracticable to obtain a large bulb of the same opacity as the smaller bulbs), was made this way in order to obtain a comparatively large space inside the tube, so that its degree of vacuum would not change too quickly. It has in front of the target a small extension, into which is fused a window of soda glass, which transmits the *x*-ray. There are two lead glass extensions made to fit on this projection, so that the rays can be directed to any part of the body and into any cavity. This tube was intended primarily for the treatment of skin lesions with the *x*-ray, but it can also be used for light fluoroscopic work and radiography.

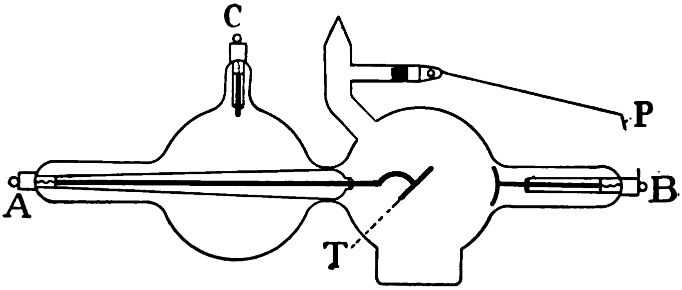

Fig. 436.—Piffard safety *x*-ray tube.

When used with a static machine, the terminal *A* is connected to the positive pole of the machine. Terminal *B* to the negative. The pointer is placed about 1½ inches away from the connection *B*. Under no circumstance should it be placed more than 2 inches away from *B*. The sliding rods 1 and 2 are separated so that the spark just disappears. Under no circumstance should they be separated more than 3 inches, and under no circumstance should the pointer be brought nearer than 1 inch to the terminal *B*. In using this tube for treatment purposes the exposure is usually much shorter than when the usual tube is used, owing to the small diameter of the bulb, and consequently, the part treated being closer to the target.

When used on an *x*-ray coil, the connections and applications above described apply, with the exception that the terminals on the coil can be separated 4 or 5 inches, never more than that. The current to excite this tube should not be very strong. If an electrolytic interrupter is used, a current of 4 or 5 amperes is all sufficient; if a mercury jet interrupter is used, a current of 2 amperes will be sufficient. The point to be specially careful about is bringing the pointer too close to the negative terminal, as if this is done it is possible to release so much gas that it will be necessary to have the tube re-exhausted. This, however, cannot occur if the pointer is at least 1 inch away from *B*, and if the *current strengths* above indicated are not *exceeded.*

Regulation of *x*-Ray Tubes for Radiotherapy.—In using the *x*-ray for therapeutic purposes the most important point to pay attention to is to so adjust your tube that the maximum number of rays generated will be absorbed in the tissue under treatment.

At the present time no standard has been universally adopted for the measurement of the *x*-ray, and until such is the case there will be a great difference in the results obtained by different operators. In a general way, a ray that when the hand is held in front of the fluoroscope shows the outline of the hand distinctly, but not the bones, would be the proper one for the treatment of all superficial skin lesions. For the treatment of a small or beginning epithelioma a ray that would show the bones of the hand black, but very distinctly, would be the best, and for internal lesions, one which would show the bones very faintly, owing to their great penetration, but the screen lighting up very brilliantly. The use of the hand as a test-object was formerly a common, though an exceedingly dangerous, custom. It is responsible for the deaths of many *x*-ray operators from cancer. A safe substitute is a preserved and mounted hand; but the Benoist radiochromometer affords a better means of measuring the quality of the *x*-ray. An *x*-ray filter may be used to arrest the less penetrating rays. Not a single treatment should be given until the operator has learned the erythema dose, or the time and distance which will produce an inflammation of the skin with his apparatus and strength of current. There are several different ways of measuring this, including the author's own. Some diseases are most favorably influenced by fractional doses of 1 H. (5 Holzknecht units produce a mild and 7 a severe dermatitis, and much more than 7 H. cause ulceration if applied at one time) or less two or three times a week. Other cases, notably of epithelioma, are best treated by massive doses of 7 H. or more, either at one session or divided

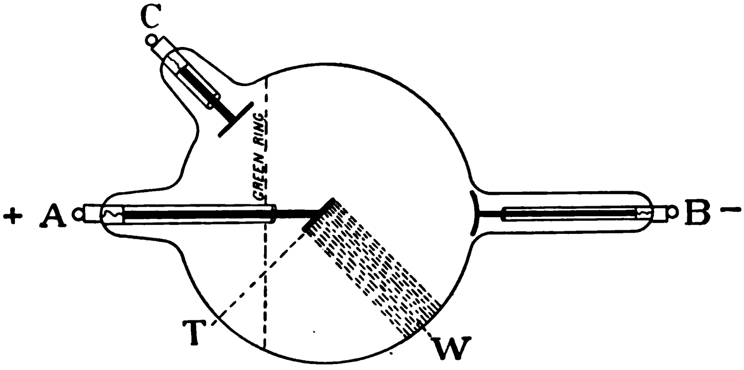

Fig. 437.—*X*-ray tube having considerable inverse current.

in two sessions not more than a day or two apart. Exact dosage is considered on p. 1052. Good results have been obtained from the use of the *x*-ray in various chronic skin diseases, skin cancers, chronic ulcers, enlargement of the lymphatic glands, uterine fibromyomata, and frequently a great deal of benefit when applied for internal cancers; in fact, the *x*-ray has been used for many chronic conditions with varying success, which will doubtless increase with the adoption of exact methods of dosage. When a tube is used with a coil, if a milliamperemeter and a valve are used and the parallel spark-gap of the tube noted, one can form some idea of the particular ray used. However, this does not tell the tale exactly, owing to the number of interruptions in the primary and the construction of the *x*-ray coil itself; still, it is a great help and is practically the best guide for the individual operator himself, for if he notes, in addition to the above facts, the number of amperes in the primary and the position of the rheostat, he can then duplicate his result on the following day. When using a tube or a coil, one of the greatest sources of trouble is the inverse current, which not only sets up a great number of wild *x*-rays, but also apparently shortens the life of the *x*-ray tube itself. This bad feature, however, can now be eliminated by means of the Villard valve. This has been improved on and made self-regulating.

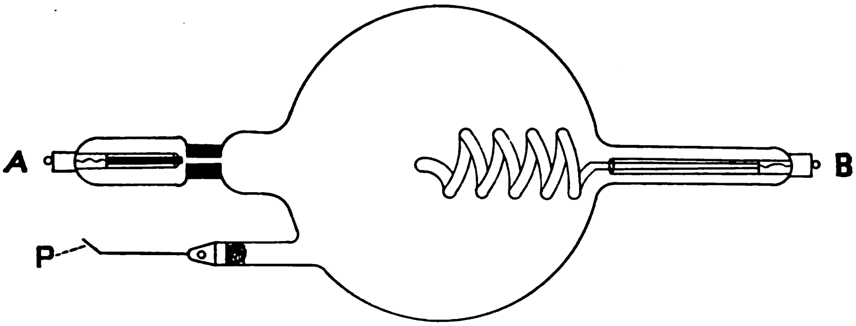

Fig. 438.—Villard valve or ventril tube.

Fig. 437 illustrates an *x*-ray tube having considerable inverse current. This is shown in the first place by the green ring, and in the second by a more intense green at *W*. While this tube would light up a fluoroscope very well, yet for taking a picture it would not be a very good tube, owing to the fact of the cathode stream from the inverse current striking the glass at *W* and causing wild *x*-rays to be generated at this point. These rays interfere with the clearness of the picture. Inverse current is most pronounced with very high-resistance tubes when excited by an *x*-ray coil. This, however, is done away with by the use of the improved Villard valve (Fig. 438). The inverse current can also be demonstrated by a little instrument known as the oscilloscope (Fig. 439). When placed in circuit with a source of high-

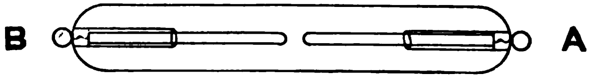

Fig. 439.—Oscilloscope.

tension current, if the current is one direction only, then it shows a broad violet band on the end which is negative (Fig. 440). If connected with an oscillating current of high tension, it shows a violet band of equal width on both sides (Fig. 441). If connected with an alternating current of high tension, but the alternations being stronger one way than the other, then it shows a broad band on one end and a smaller

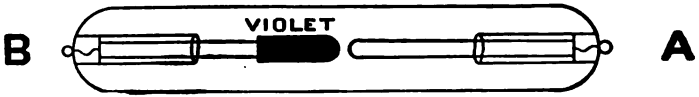

Fig. 440.—Oscilloscope with unidirectional current.

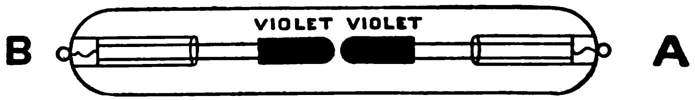

Fig. 441.—Oscilloscope showing current with equal alternations.

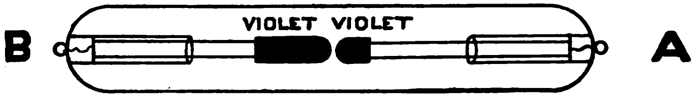

Fig. 442.—Oscilloscope showing an alternating current stronger in one direction than in the other.

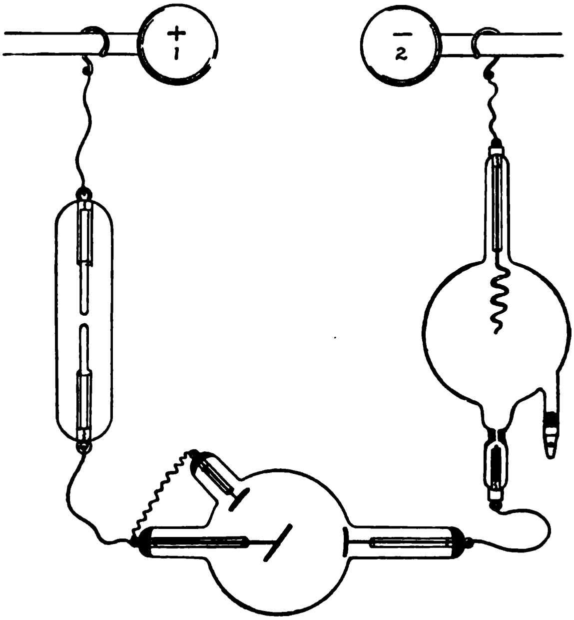

Fig. 443.—*X*-ray tube connected in circuit with oscilloscope and Villard tube.

band on the other end, as in Fig. 442. This device is especially useful in connection with the Villard valve, as it will show whether the valve is in good working order and cutting off all of the inverse current, in which case the oscilloscope will have the appearance as shown in Fig. 440.

When a tube has been punctured or broken, so as to admit a considerable amount of air at atmospheric pressure, this fact is indicated by a spark passing from the aluminum cup to the target. If, however, the regulating device has been used with too strong a current or for too long a time, then the tube shows a violet color throughout the entire bulb, and this is also the appearance when a tube has become a leaker. In both these conditions the only thing to do is to send the tube to the maker and have it re-exhausted. If it is an expensive tube it will very likely give better satisfaction if you send the electrodes to the maker and have a new tube made, using the old electrodes.

Fig. 443 illustrates the way to connect an *x*-ray tube in circuit with an oscilloscope and a ventril tube.

Care of the Fluoroscope.—A fluoroscope (Fig. 444) requires, in the first place, to be kept in a moderately cool place. It should also have a cover made to go over the eye-piece, so that when not in use no dust or dirt can fall on the screen, as the screen is made of one of the most sensitive salts and a very little dust will cause it to decompose, thus losing its fluorescent property. A sheet of lead glass over the screen protects this and also the observer's eyes. After a varying length of time the screen begins to deteriorate at the edge. This *deterioration* is indicated by a change of *color*. When the screen is new and in good condition it will have an apple-green color; as it begins to deteriorate, the edge will begin to turn color, and this will extend finally over the entire screen, it being an orange brown. This change is gradual, and as it occurs the fluorescence of the screen diminishes; however, it does not cease entirely, so that it frequently happens that a physician finds that he is not able to see as well with the fluoroscope as formerly, and he will imagine that there is something the matter with the tube or the *machine*. He most often concludes that the trouble is with the tube, and will order a new tube, but he fails to get a better result, owing to the fact that the trouble lies with the screen and not with the apparatus. A hand-guard of zinc protects the operator's hand.

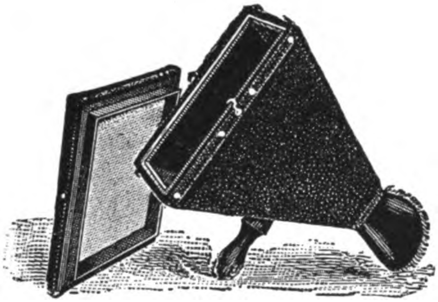

Fig. 444.—Cryptoscope or box fluoroscope.

Fluoroscopy.—In the first place, remember that the *x*-rays are *invisible* and that the green fluorescence of the tube is due to the cathode-rays and *x*-rays which strike against the glass, causing it to fluoresce.

A tube made of lead glass instead of fluorescing *green*, fluoresces *blue*. The platinobarium cyanid crystals when struck by the *x*-ray fluoresce, and it is this effect that we see and not the *x*-ray itself. The more *penetrating* the rays are, the more *brilliant* will usually be the screen. When the hand is held on one side of the screen then the *x*-rays act as follows: Part of them strike the screen directly. This causes the screen to fluoresce at its maximum. The rays that are in line with the soft parts of the hand, part of them are absorbed and part pass through and strike the screen, so that the screen directly under the soft parts does not fluoresce as brightly as where there has been no absorption of the rays; consequently, this portion of the screen appears somewhat darker. The rays that are in line with the bones are practically all absorbed, assuming that we have a very soft tube, and consequently the screen directly under the bones does not fluoresce at all, so that it appears black.

From this description you will appreciate the fact that using the screen amounts practically to *transillumination*; consequently, in order to do the *best* fluoroscopic work it is *absolutely* necessary to have a practically *dark* room, and to be in the room for at least five minutes before attempting to use the fluoroscope. The tube should be one in which the *penetration* of the rays can be *varied*. In order to obtain the best detail, rays of the *least* penetration that will be *sufficient* to go through the part to be examined will give the *greatest* amount of contrast. A 32-candle-power ruby lamp in a large room or a 16-candle-power ruby lamp in a very small room will give ample light to work in an otherwise perfectly dark room and interferes very little with the use of the fluoroscopic screen. For the most exact work, however, the rooms should be entirely dark when an uncovered screen is used, or if this is impracticable, the usual box fluoroscope must be used. In any case daylight should be excluded.

Fig. 445.—The Johnston fluoroscope. The operator stands at one side instead of in a direct line with the rays.

Cathode Rays.—The cathode stream has certain properties which it is necessary to explain in connection with those of the *x*-ray. Everything points to the conclusion that it is a stream of material particles traveling at the rate of about 20,000 miles a second. This is only the average velocity. Each particle travels at a rate of speed depending partly upon its size and partly upon the voltage under which it is impelled. Many of the cathode particles encounter ions, atoms, and molecules which arrest their motion toward the anticathode.

Some of the particles forming the cathode ray are probably electrons and carry the same amount of negative electricity as hydrogen atoms in an electrolytic liquid ($\frac{7}{10,000,000,000}$ electrostatic units, or $\frac{2.3}{10,000.000,000,000,000,000}$ coulombs), and their size is about $\frac{1}{1000}$ or $\frac{1}{2000}$ that of a hydrogen atom. Other cathode particles are probably aggregations of electrons and others molecules or aggregations of molecules. The particles start perpendicularly from every point on the surface of the cathode and proceed in straight lines until they strike some solid substance. They are deflected toward a horseshoe magnet and exercise a certain amount of mutual repulsion. Consequently in an *x*-ray tube the focus point upon the anticathode is much further from the cathode than would be the case if the cathode rays starting perpendicularly to its surface proceeded in perfectly straight lines and therefore met at its center of curvature. The impact of the cathode stream produces motion, and will turn a pinwheel placed inside the vacuum tube. It produces sufficient heat to melt the platinum disk in an *x*-ray tube. It produces fluorescence of the glass wall of the tube and of many other substances; some of the phosphorescent colors produced are: with sulphate of copper, a faint green; with sulphate of copper containing a trace of sulphate of manganese, a bright green; none with sulphate of strontium; with sulphate of strontium containing a trace of sulphate of manganese, a bright red; with barium sulphate, a faint dark violet; with barium sulphate containing a trace of sulphate of manganese, a dark blue; with magnesium sulphate, a red; with magnesium sulphate and a trace of sulphate of manganese, an intense dark red; with sulphate of zinc, a bluish color; with sodium sulphate containing ½ of 1 per cent. of sulphate of manganese, an intense brownish yellow; with cadmium sulphate, a yellow; with fluorid of calcium, a faint blue; with fluorid of calcium with a trace of hydrid of manganese, an intense blue. The most striking effects, as may be seen above, are on "solid solutions." These are formed by two salts, one greatly in excess of the other, precipitated simultaneously from a watery solution. The cathode rays produce upon the glass wall of the tube shadows of any solid body which may intercept their path through the vacuum. They render any gas through which they pass a conductor of electricity. They carry a charge of negative electricity and any solid substance which they strike gives out generally diffused, not alone perpendicular, cathode rays, and also *x*-rays. Cathode rays do not emerge from a glass vacuum tube in any appreciable amount unless a thin sheet of aluminum is hermetically sealed into an opening in the glass. The aluminum is transparent to these rays and acts as a sort of window if placed at the spot where the cathode rays impinge.

Herz's discovery that the cathode rays, as he thought them to be, would penetrate gold-leaf, was made by covering a small piece of uranium glass with gold-leaf, leaving an uncovered edge of glass exposed all round. Bringing this piece of glass near the tube and opposite the cathode pole, he found that the piece of glass which was uncovered became fluorescent and that it increased the vacuum still more within the tube, even the glass back of the gold-leaf was rendered fluorescent. This apparently was an effect of the *x*-ray, but at that time (1892) it was not recognized as such. Lenard, a couple of years later, in his experiments with the rays that go by his name, found that phosphorescence was sometimes caused even beyond substances like aluminum.

If the aluminum is .00265 millimeter thick the rays pass through in sufficient amount to cause visible light and produce phosphorescence. The most phosphorescent substance, according to Prof. J. J. Thomson (now Sir Joseph Thomson), whose book on the "Transmission of Electricity through Gases" is a recognized source of information, is tissue-paper soaked in pentadekylparatoleketon. These cathode rays outside the tube are called Lenard rays. They spread out very diffusely and produce shadows larger than should occur geometrically. They cause photographic effects, are arrested by quartz, but alum is transparent to them. But some of these effects may be due to the presence of the *x*-ray. Lenard rays discharge negatively or positively charged bodies, as do the *x*-rays.

Cathode rays may be shown in an ordinary electric-light bulb by connecting one wire with a piece of tin-foil pasted on the outside of the bulb at a distance from the metal part of the bulb. The latter is connected with the other electric-light wire. This experiment and the other, of making the same connections between the bulb and the wires from an *x*-ray coil, generally result in burning out the incandescent filament and spoiling the lamp. The vacuum in electric-light bulbs is too low to generate *x*-rays.

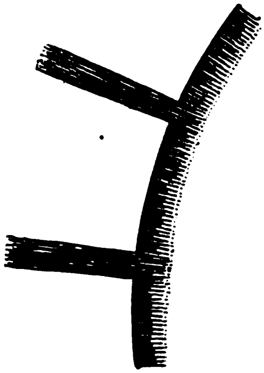

Fig. 446.—Kanalstrahlen or channel rays.

Kanalstrahlen, or **channel rays,** were discovered by Goldstein in 1886, who found that with a perforated cathode (Fig. 446) certain rays occurred behind the cathode which did not seem to be deflected by a magnet, and whose only known property is that of being accompanied by luminosity. Thomson's explanation of these is that they are jets of phosphorescent gas produced by a sort of explosion at the cathode.

Recent experiments by Wien and by J. J. Thomson[1] have shown that the kanalstrahlen of Goldstein are charged with positive electricity. They are deviated by a magnetic field or by an electrostatic field in the opposite direction from that followed by the cathode rays. But the magnetic field must be very much more powerful and the means of observation much more exact than in the latter case.

Channel rays may be studied by having an enlargement of the tube back of the cathode, containing a fluorescent screen. They carry a positive charge of electricity, and their deflection by a magnetic field is evidenced by the displacement of the fluorescent spot on the screen.

Channel rays ionize gases through which they pass.

Ionization by Cathode and by Channel Rays.[2]—The cathode rays in passing through an atom repel or attract the corpuscles which are con-

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[1] Le Radium, June, 1907.

[2] Sir J. J. Thomson, Phil. Magazine, 23, 1912, 449.

tained therein and communicate kinetic energy or motion to them. If this energy reaches a certain value, a corpuscle escapes from the molecule in such a way that there is a production of a free corpuscle and of a positively charged atom.

A **Wehnelt cathode** is one covered with lime and heated and has a hole in it. It affords channel rays in abundance, and is suited to the production of very soft *x*-rays with a current of 1000 volts or less.

Positively Charged Particles in a Vacuum Tube.—As intimated in the last paragraph, it seems moderately certain at the present writing that there are such things as positively charged particles in motion inside a Geissler tube which has a vacuum of about $\frac{1}{1000}$ atmosphere or a Röntgen tube which has a vacuum of about $\frac{1}{1,000,000}$ atmosphere. If this be really so, it does not necessarily interfere with our conception of the cathode stream, but it may to a certain extent cause us to revise our idea that the latter is practically the sole factor in the transmission of electricity through gases and that the current is unidirectional, from the cathode to the anode.

The **energy of the *x*-rays** is $\frac{2\frac{1}{4}}{1000}$ that of the cathode rays which produce them (M. Wien).

The energy of the *x*-ray is proportional to the energy of the cathode rays producing it. The energy of a cathode particle is proportional to the fourth power of its velocity.

Conversion of *x*-Rays into Heat.—The absorption of the *x*-ray in passing through a sheet of metal causes a certain amount of energy to be converted into heat. Adams[1] has measured this amount of heat by very delicate apparatus.

Some of his results agree with observations made upon the *x*-ray by other workers with different methods. These are: the percentage of *x*-ray absorbed is independent of the intensity of the radiation; there is very little surface effect like that which reflects or disperses or absorbs ordinary light; a smaller proportion of the *x*-ray is absorbed by a second similar metallic sheet than by the first one; but this does not hold good in the case of *x*-rays passing first through aluminum and then through silver; they are less penetrating for silver than normally.

An observation made by Adams' thermometric method which differs from that supposed to be shown by other methods is that the amount and quality of radiance which passes through two sheets of different metals is the same no matter in what order they are placed. According to this observation the *x*-ray undergoes no change in quality in passing through different metals.

The original radiation consisting of rays of less penetrating power and rays of more penetrating power encounter a sheet of metal which stops a greater proportion usually of the less penetrating rays. The rays which pass to the second metallic sheet penetrate this in greater proportion, not because they are rays which have been rendered more penetrating by passage through the first metal, but because they are the original more penetrating rays from which the less penetrating rays have been separated by the first sheet of metal.

Assuming his observation about the different metals to be correct, we should draw the following conclusions:

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[1] Proc. Am. Philosoph. Soc., Dec. 29, 1906.

While it is true that some metals, like silver, absorb different wave-lengths of the x-ray from other metals, like aluminum, there is no change in the x-ray, and the total portion arrested is the same no matter in which order the metals are placed and in which order the different wave-lengths are arrested.

The present author has always felt that this was probably true, but, of course, to be theoretically modified by the consideration of secondary rays, usually of low penetration.

X-rays Within the Vacuum Tube.—Experiments by Battelli[1] showed that a photographic plate in a light-proof envelope was not affected when inside an x-ray tube in operation. This would indicate that with the tube employed the x-rays radiated chiefly if not altogether from the external surface of the glass tube. This experiment should be repeated by a number of observers because the result appears paradoxic.

Measurement of Velocity of x-Ray.—E. Marx's method[2] employs the same current to excite two vacuum tubes, one an ordinary x-ray tube and the other a tube exhausted to an extremely high vacuum. The x-ray shines upon this second tube, and if the x-rays strike upon the cathode of this tube it excites secondary x-rays. The combined effect of the primary and secondary x-rays in the second tube is greatest when the impact of the exciting cathode particles and of the exciting x-rays from the other tube are synchronous. A series of experiments is made, varying the length of the conducting wire between the two tubes without altering the distance between the tubes themselves. The result shows that the velocity of the x-ray in the air is the same as that of electricity in copper wire, about 185,000 miles a second.

Discharge Rays (German Entladungs Strahlen).—An electric spark, even in the open air, gives origin to radiations which produce thermo-luminescence and also ionize gases. They have something like the penetrating properties of the x-ray. Laird [3] finds that these rays originate chiefly from the vicinity of the cathode and that they do not deviate under the influence of a magnetic field. They resemble the x-ray in the fact that they are discontinuous vibrations, not a uniform succession of waves like those of light.

FORMS OF ELECTRIC GENERATORS ADAPTED TO EXCITING AN X-RAY TUBE

The Static Machine.—The simplest form of apparatus is a static machine, and any large and powerful one will produce quite a good x-radiance. The static machine produces, directly, currents of very high voltage and very very low amperage, rapidly interrupted, all in the same direction, and of very uniform intensity. All that is necessary is to connect the prime conductors of the static machine with the corresponding electrodes of the x-ray tube. Multiple spark-gaps should be ready for use upon each of the cords leading to the tube, and a very useful bit of apparatus is a pole-changer, by means of which the polarity of the conducting cords may be changed. The polarity of the static machine cannot be changed at will and the polarity of the x-ray tube cannot be changed at all. Sometimes it is inconvenient to place the tube in such a position that a cord can pass directly from its negative pole to the negative pole of the static machine and in such a case the

[1] Nuovo Cimento, April 18, 1896.
[2] Phys. Zeit., No. 11, 1910, 958.
[3] Phys. Rev., 33, 1911, 512.

connection is made indirectly by means of the pole-changer. To do satisfactory work a static machine, must have at least eight revolving plates, 30 inches or more in diameter; and a motor, either water or electric, by means of which the plates may be made to revolve 250 or more times a minute. The larger and more powerful the machine, the better x-ray work can be done with it. Williams states that the static machine used for x-ray work at the Massachusetts General Hospital in Boston has revolving glass plates whose combined weight is a ton or 2000 pounds. The static machine has certain limitations: it is not suitable for warm or damp climates; it is uncertain in action in damp weather, although this may be obviated by care in construction and maintenance, the author's machine having never refused to work winter or summer, rain or shine. It usually gives a relatively small amperage and so takes about five times as long to make a picture as a coil does; it is, in that case, unsuited for radiography of the thicker portions of the body. It gives a steady brilliant radiance which is excellent for fluoroscopic examinations and produces less of the photochemic rays than the coil, and is less likely to produce dermatitis in either patient or operator during such examinations. It is less suitable for radiotherapy because of the longer exposures required; and it is especially necessary to note that some of the worst accidental burns that have come to the author for treatment have been produced by the static machine. It can be used in places where there is no electric current obtainable. Its cost for equally good radiographic results is very much greater than that of a coil.

The Baker static machine has revolving plates, made of a dozen sheets of linen paper soaked in shellac and compressed into a disk as hard as iron, but without its brittleness. The plates may be made larger and revolve at a much higher speed than glass plates. The machine produces an excellent x-ray, but not so powerful as that from a transformer or an unfluctuating converter.

The static machine gives a more uniform discharge and, according to some observations, it may with a tube of a certain degree of vacuum give x-rays of much more nearly a single rate of vibration than the induction-coil with its discharge varying at every instant. Piffard[1] and others conclude from this that the static machine is preferable to the induction-coil for radiotherapy.

Milliamperage of a Static Machine When Used for x-Ray Work.—Contrary to what is commonly the case with an induction-coil, the milliamperemeter shows more current passing from a static machine when the resistance of the x-ray tube is great than when the vacuum is low and the resistance small. Two factors are concerned: one is that the output of the static machine is at its maximum when its prime conductors are far apart and the resistance is as great as possible; another is that static electricity is of such high voltage that a brush discharge from the terminals of the tube or any other metal points in the circuit allows more current to go through the milliamperemeter than gets through the tube if the vacuum is high.

Increasing the resistance in the circuit by raising the degree of vacuum in the tube increases the output of the static machine, but much of this increase is wasted.

Increasing the resistance in the circuit by the introduction of a spark-gap increases the output without increasing the resistance of the

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[1] New York Med. Jour., Sept. 16, 1905.

tube, and consequently the increased output is directly available for increasing the intensity of the x-ray.

Parallel Spark Backed Up by an x-Ray Tube Actuated by a Static Machine.—The same x-ray tube which will back up a spark of about 5 inches with an induction-coil will back up one of only about 1 inch with a static machine. The author regards this as attributable to the greater loss of high-tension static electricity by a brush discharge from the terminals of the tube and from metallic points about the conducting cords.

Regulating the Vacuum of an x-Ray Tube for Use with a Static Machine.—If one has only a static machine the tube employed should be one furnished by the manufacturer in good condition for use with this current. It will doubtless remain in perfect condition for a very long time, because this discharge does not usually heat up the tube and so cause absorption of molecules of gas. A tube for use with a static machine need not, therefore, be provided with a regulator, but may be sent to the manufacturer to be opened and re-exhausted once in a month or a year, according to the amount of use. If the tube is furnished with an osmo regulator, this should be used very rarely indeed and very cautiously. Lowering the vacuum a very little too much will unfit the tube for use with the static machine, because the current has not amperage enough to scatter particles of metal through the tube and so absorb an excess of gas. If there is one of the spark regulators it will often be found necessary to connect the negative wire directly with the vacuum reducer and not depend upon leaving the negative conducting cord attached to the cathode and turning the spark rod toward it. Even with a direct connection it may be found that the amperage of the current is insufficient to liberate the necessary amount of gas.

If one has an induction-coil as well as a static machine, it is an extremely easy matter to regulate the vacuum in the tube by the use of the induction-coil and then to use the static machine to run the tube. This might be done for some treatment or experiment where a long, mild, uniform exposure was desired.

If *Leyden jars* are used to actuate an x-ray tube with a static machine they should not be larger than pint bottles. The internal armatures are connected with the prime conductors and the external armatures with the poles of the x-ray tube.

The *voltage from a static machine* is very high and is measured by the distance across which a spark will pass between the two poles or by an electrostatic voltmeter or, indirectly, by an electrometer. The latter is a refinement of the simple electroscope, in which the two gold leaves separate when they both become charged with the same kind of electricity by bringing a charged body near the rod from which they are suspended. The electrometer shows the density of the electric charge at any part of the apparatus or of the patient, and this varies with the voltage of the source of electricity and is also greatest upon the surface and especially upon sharp projections from the surface. The voltage produced by a good static machine is 100,000 or more. The amperage is very small indeed, but is still demonstrable by means of a milliamperemeter of the movable wire coil variety (d'Arsonval milliamperemeter) or by a pole detector in which the electrolytic effect of the current produces a red color in the liquid. The physical and physiologic effects of the static discharge are due almost entirely to its tension or voltage and scarcely at all to its intensity or current strength or amperage. It has polarity, however, and the proper direction of the current is necessary for the excitation of an *x*-ray tube.

An Induction-coil Operated by a Galvanic Battery.—The battery should be the equivalent of 30 to 60 Leclanché cells (8 to 16 cells will do) connected in series, and the current from this should pass through the primary coil of thick copper wire surrounding a core of soft-iron rods. The primary coil is slipped inside the secondary coil, to which it is not connected in any way. The secondary coil consists of thousands of turns of very fine copper wire carefully insulated and terminating in two poles from which the conducting cords are to lead to the *x*-ray tube. Each time that the current begins to flow through the primary coil a wave of electricity is induced in the secondary coil, and again when the current is turned off. The break-current induced in the secondary coil is stronger and in an opposite direction from the make-current. The primary current is turned on and off very rapidly by a vibrator. When the current is turned on, the primary current causes the soft-iron core to become a temporary magnet and this attracts the iron armature, whose motion toward the core breaks the contact and the current ceases. The iron core ceases to be a magnet and the armature,

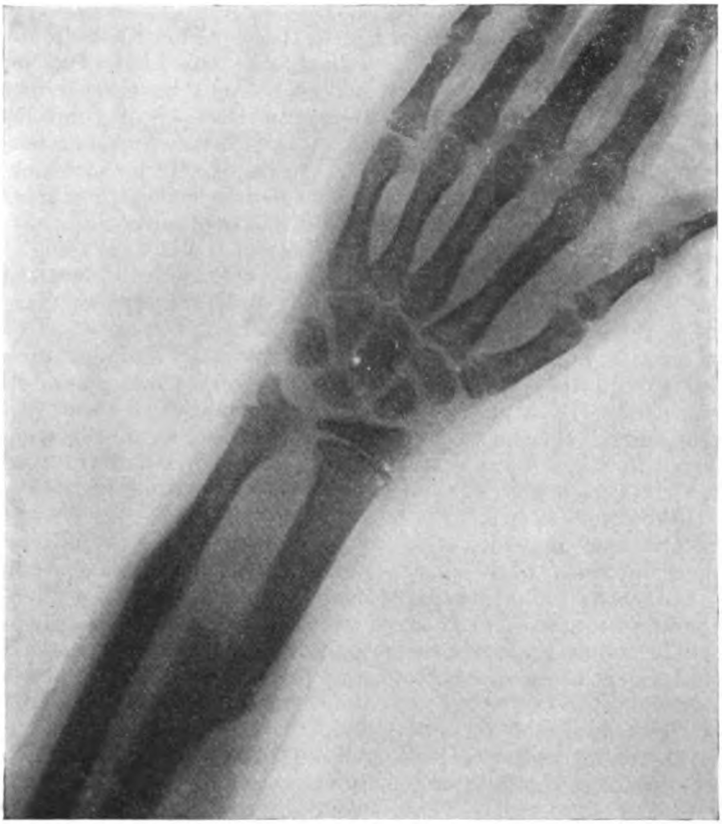

Fig. 447.—Radiograph made with coil actuated by a battery of galvanic cells.

which is upon a spring, returns to its original position and the contact is again made. Such a coil requires a condenser of many sheets of lead foil separated by sheets of mica or paper to take up the extra currents occurring in the primary coil.

The value of a condenser for an induction-coil used to excite an *x*-ray tube except with an electrolytic interrupter is easily demonstrated. The interrupter works more steadily and the fluoroscopic and radiographic results are much better. Treatments and the lighter forms of fluoroscopic and radiographic work may be very well done with such a coil. Fig. 447 was made with a coil and galvanic battery in 1896 by Dr. T. W. Kilmer, then one of my assistants at St. Bartholomew's clinic.

An Induction-coil and Storage-battery.—The 100-volt storage-battery of an electric automobile will operate any kind of a coil and interrupter. The storage-battery itself need not be carried into the room in which the coil is placed. It is only necessary to run a double, heavily insulated wire from the charging plug of the automobile to the *x*-ray apparatus. The smaller portable storage-batteries in which each cell weighs about 40 pounds operate an 8-inch coil with a mechanic interrupter very well. About six such cells are required and they have to be sent to a power-house to be recharged when exhausted. This form of apparatus has given me satisfactory service in the treatment of cases at patients' homes where there was no electric current. In such cases it is much more practicable than a galvanic battery. The rent of such a battery of six cells is only about ten dollars a month, including recharging, and they may be obtained in every town where electric power is used. Their capacity is 30 ampere hours. The efficiency is not great enough for the heavier kinds of radiography and it would not be selected for office work if an electric-lighting current were available. It forms the best practicable portable source of current for *x*-ray work where there is no electric light.

The principle on which a storage-battery operates is quite simple. Two pieces of sheet lead separated by strips of asbestos are wound up into a concentric coil, the space between the two leads is filled with dilute sulphuric acid, and there is a wire connected with each of the leads. The whole apparatus is so constructed that the two leads are insulated except as far as a current may pass through the liquid between them, or when the two wires are connected. To charge such a battery a 10- or 12-volt direct current derived from the electric-light current or from a galvanic battery is passed through it for some hours. Electrolysis takes place in the fluid and the positive and negative nascent gases combine with the very large lead surfaces forming the two poles of the battery, and on disconnecting the battery it is found that this difference in the chemic composition of the two lead surfaces remains permanent until an electric current generated in the storage-battery itself is permitted to pass by connecting their two wires together either directly or through some apparatus. The tendency is for a reverse chemic process to take place by which the two lead surfaces become exactly similar in composition again, both being bathed in the same chemic fluid. This chemic change produces a current just as in a galvanic battery. A storage-battery then is like an ordinary galvanic battery, except that the difference between the two elements is not originally present, but is produced by a powerful current of electricity, and when exhausted may be renewed by the same means. The efficiency of a storage-battery is very much greater than that of a galvanic battery. Improvements in storage-batteries have consisted in having the lead plates coated with some chemical which adds to the efficiency. Like everything else, however, a storage-battery finally wears out, there is a limit to the number of times it can be recharged. Some rheostat resistance should always be used because of the possibility that the interrupter may stick and a continuous heavy current burn out the *x*-ray coil or damage the storage-battery. The plates in the latter may "buckle."

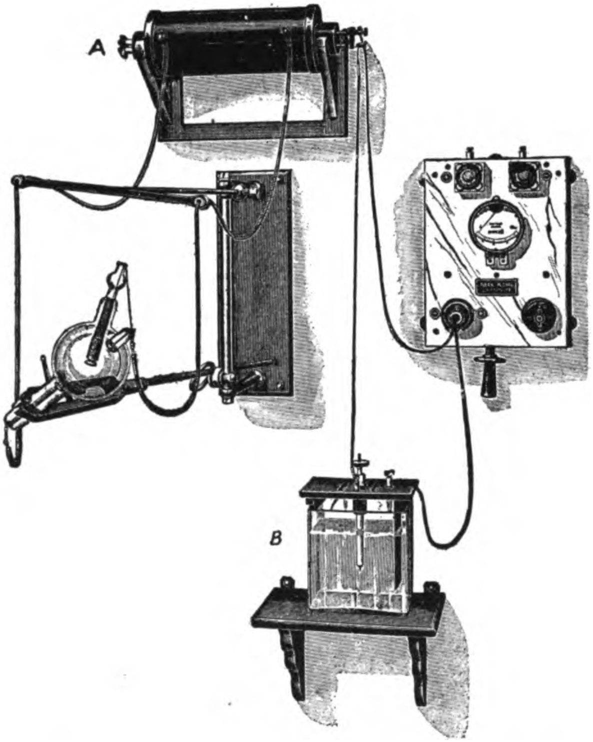

Fig. 448.—*X*-ray wall installation with Wehnelt interrupter.

An Induction-coil Operated by the Electric-lighting Current.—This is one of the most practicable and satisfactory methods (Fig. 448, *A*). The current generally used is the 110-volt direct current, though the alternating current may be used with a slight change in the apparatus. The apparatus is connected at any ordinary electric-light socket, the current passing through an interrupter which makes and breaks the current several hundred or several thousand times a minute. Some interrupters used are mechanic, depending on an electromagnetic vibrator, or on the making and breaking of the contact between mercury and a solid metal. The metal may dip into the mercury and be withdrawn or, what is much more satisfactory, a whirling jet of mercury may strike against metal plates fixed in the insulated wall of the vessel surrounding the mercury turbine. Either of these mercury interrupters requires a motor to operate it and requires a greater amount of attention than the electrolytic interrupter.

Electrolytic interrupters (Fig. 448, *B*) depend upon a principle enunciated by Spottiswood, in 1876, that when a current of electricity is passed through a liquid and one of the metallic electrodes is very small the surface of this electrode becomes covered with a layer of heated gas or vapor which interrupts the flow of the current. The current stopping, the gas or vapor is dissipated and the current begins to flow again with the same result.

These depend upon the thermal effect of an electric current when it passes through a liquid path with a very small cross-section. The current will not cause excessive heating if it passes from one large metal plate to another submerged in a liquid which is a good conductor of electricity. But when all the current has to pass through the small amount of liquid represented by a pin-hole in a porcelain jar or by the fluid in contact with a small platinum point, the resistance of a frictional character becomes so great that the liquid not only boils, but is converted into a mass of incandescent gas. This effectually destroys the electric contact between the liquid and the platinum point in one type of interrupter; or between the two bodies of liquid in the other type. In either case the good conducting path afforded by the dilute acid liquid is broken by the introduction of a mass of gas which arrests the whole or a very large part of the current. No sooner has the current ceased to flow than the incandescent gas disappears. It partly collapses under the pressure of the liquid or rises to the surface in bubbles. The flow of the current is no longer obstructed, but its reëstablishment is attended by the formation of a fresh mass of incandescent vapor and a new arrest of the current. In this way interruptions are produced at regular intervals and of a character extremely well suited to *x*-ray and high-frequency currents. The smaller the surface of platinum exposed in the Wehnelt and the smaller the holes in the Caldwell-Simon interrupter[1] the more rapid the interruptions and the weaker the primary current, and, generally speaking, the weaker the *x*-ray or high-frequency current excited by the secondary current.

Electrolysis takes place in either of these interrupters with the liberation of hydrogen gas at the negative and oxygen gas at the positive electrode, and there is some liability to an explosion if the two gases are allowed to mingle in a confined space and then become ignited by a spark at some loose electric contact. The result is more disagreeable than dangerous, the cover of the box being thrown a few inches into the air and the dilute acid being spattered over neighboring objects. There is no means of absolutely preventing such an explosion, but its occurrence may be made very unlikely by certain precautions. The interrupter jar should not be tightly closed. If it is covered at all, there should be an ample opening for the escape of hot sulphurous fumes produced by the current. This results in a general diffusion of the oxygen and hydrogen in the air of the room instead of their being confined in a concentrated and explosive form in a small space. The noise and sulphurous fumes thus allowed to escape from the interrupter

[1] Caldwell, in America, and Simon, in Europe, invented this type of interrupter with holes in a diaphragm between the two halves of a vessel containing the electrolyte. Pusey and Caldwell also figure in their excellent book an interrupter in which the size of the communication is regulated by a conic point pushed through the hole to a greater or less distance. The present author believes that he was the first to publish (Medical Record, New York, October 24, 1903) an account of this type of interrupter in its simplest and best form, "the Beaker Interrupter." He makes no claim to originality.

are disagreeable, and so it will be found desirable either to place the interrupters in another room or in the fireplace and cover them by a wooden cabinet open behind to allow the fumes to pass up the chimney. Liquid interrupters may be placed at any distance from the x-ray coil, but, of course, it is necessary to have them where they will be accessible for purposes of regulation during the operation of the apparatus. The liquid gradually becomes heated and after it has reached a certain temperature the interruptions become irregular. There will be a series of interruptions, then a complete pause for a time, and then the regular interruptions. The x-ray flickers in consequence and becomes less effective. A stronger current must be turned on in order to secure regular interruptions and a good therapeutic or diagnostic effect, but after a temperature of about 80° C. is reached the interrupter will be apt not to work at all. If the current is to be used for a long time, as for a series of treatments by high-frequency currents, some arrangement must be made to prevent overheating the liquid. The author uses five independent interrupters, the current being changed from one to the other by a switch right at the x-ray coil, although they are in another room. Or a very large jar can be used holding 2 or 3 gallons of liquid which will heat up very slowly. Or a coil of tubing may be placed in the liquid and a current of cold water sent through it to keep the electrolyte cool. Having several interrupters accomplishes the result very well and, in addition, gives one a great variation in quality of current, and the wearing out or the accidental destruction of one of the interrupters leaves the other interrupters to fall back on. In the author's outfit there are two Caldwell-Simon interrupters with holes of different sizes, two Wehnelt interrupters with platinum points of different thicknesses and with a different electrolyte in each, and a mechanic interrupter of the *wheel* type. The different Caldwell-Simon interrupters yield a uniformly interrupted current of from 4 to 10 amperes, according to the amount of resistance in the rheostat and of self-induction in the primary coil. The electrolyte in these two interrupters is the same—1 part of sulphuric acid and 6 of water, making a solution with a specific gravity of about 1.2. The Wehnelt interrupters are adjustable as to the length of the platinum point exposed and transmit a uniformly interrupted current of from 2 to 25 or 30 amperes under varying conditions. The electrolyte is sulphuric acid 1 part to 6 parts of water. A substitute may be 1 part water and 1 part saturated solution of Rochelle salt in water, a small amount of sulphuric acid having been added. The Rochelle salt alone in the electrolyte does away with the disagreeable fumes, but its solution is not nearly as good a conductor of electricity as dilute sulphuric acid, and consequently the current is weakened and much more heating of the liquid occurs; and it becomes quite a task to frequently open the jar and pour in water to make up for the rapid evaporation. The platinum in each is a cylindric rod about 1 mm. in thickness, and a greater or less length is protruded from its porcelain sheath by turning an insulated knob at the top of the hard-rubber tube in which it is held.

With the Caldwell-Simon interrupter the polarity of the current makes no difference; but with the Wehnelt interrupter it is essential that the positive battery wire should lead to the platinum point; and if the wrong connection is made, the interruptions are irregular and the sound is rough and deep and the platinum is much more rapidly worn away.

The cause of this is probably the formation of a sheath of hydrogen gas upon the surface of the platinum when it is connected with the negative wire, and this sheath presents great resistance to the electric current. This hydrogen sheath forms a barrier even when a large portion of the platinum is exposed, and it produces more continuous resistance than the intermittent disconnection which is desired. This electrolytic effect is separate from and additional to the thermal effect due to the smallness of the liquid conducting path at that point and the consequent ohmic resistance or friction.

The Wehnelt interrupter is the only one which may be directly connected with and will partly rectify an alternating current. It works fairly well, but, of course, the platinum point has an undesirable polarity half of the time and wears out much sooner than it would if it were connected with the positive wire all the time.

All the other types of interrupter for induction-coils require that alternating currents shall be rectified or made unidirectional in order that they can be used, and it is better to do so even with the Wehnelt interrupter The different means of rectifying the current will be described in another part of this book.

The *Wehnelt interrupter* (Fig. 449) is exactly on this principle, the fluid being sulphuric acid diluted with six times as much water, the large electrode is of lead and the small one is of platinum wire enclosed in very tough porcelain. By means of a screw adjustment a larger or smaller amount of the platinum may be caused to project beyond the porcelain and the electric impulses made small and rapid if little of the platinum is exposed; and heavier and less rapid if a greater length is exposed. The platinum should always be connected with the positive wire. Such an interrupter works well with the direct 110-volt current and over a range of from 5 to 30 or even 40 amperes. It does not work after the fluid becomes overheated, so it is necessary to have two or more if the apparatus is used continuously.

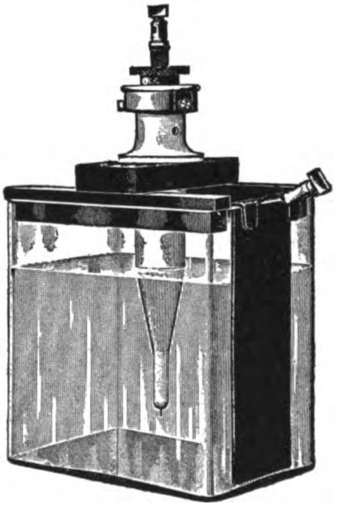

Fig. 449.—Wehnelt interrupter with one platinum anode 0.039 inch thick.

Caldwell or Simon Interrupter.—The other type of electrolytic interrupter is exemplified by the Caldwell or Simon interrupter, in which there are two large lead electrodes dipping into dilute sulphuric acid, the vessel containing which is divided by a vertical partition. The current passes through pin-holes in this partition and the liquid conductor at these narrow plates, of course, presents great resistance, the liquid is heated, and a mass of vapor cuts off the current.

The most practical interrupter of this type is a beaker interrupter made for me by Wappler, under Caldwell's patent, and first published I believe in my article of October 24, 1903 (Medical Record). "This consists of a large porcelain jar, partly filled with dilute sulphuric acid in which is set a smaller jar with a pin-hole (three holes are better) orifice near the bottom. One conducting wire terminates in a leaden ring resting in the acid in the outer jar. The current passes through the liquid and the punctured jar to the leaden plate resting in the acid in the inner jar, from which it passes by a conducting wire to the rheostat, and then through the primary coil and thence back through the negative wire to the wall socket."

The Wehnelt interrupter works with an alternating current, but not so well, and with more rapid wear of the platinum than with the direct current. The platinum really ought to be the positive pole, and with an alternating current, of course, it is the negative pole half the time. For x-ray work with an interrupter of the Caldwell type the alternating current must usually first be changed to a direct current. This can be done by means of a motor generator, which is really a dynamo run by an electric motor, or of a mercury arc rectifier, in which the current passes through mercury vapor which permits the passage of the currents in only one direction, the alternate currents being suppressed. Either of these means is effective and would be chosen for an office outfit, but for an outfit at a patient's home the simple and inexpensive aluminum cell in which the fluid is a 6 per cent. solution of Rochelle salt or of sodium bicarbonate, and one electrode is of lead and the other of aluminum or carbon, suppresses the alternate current perfectly well for treatment and for all but the heaviest and most rapid radiography.

Aluminum Cell Electrolytic Rectifier.—It transmits about 90 per cent. of the currents passing in one direction and very little of the currents in the other direction. The jar should be capable of standing a certain amount of heat. This enables one to use the Wehnelt interrupter without undue consumption of the platinum point; and either the Wehnelt or the Caldwell interrupter with good functional results in the illumination of an x-ray tube. It has been described in the preceding paragraph.

Crookes's film is a layer $\frac{1}{1000}$ inch thick which forms upon the lead surface in the electrolytic rectifier and acts as an enormous resistance to the flow of current in the wrong direction.

The current can only flow freely when the lead electrode is connected with the positive pole of the source of electricity.

The lead in the electrolytic rectifier should, therefore, be connected with the lead in the Wehnelt interrupter.

Grisson's rectifier is an aluminum cell in which the other electrode is of iron or some other indifferent metal. When the aluminum is positive it is covered by bubbles of oxygen and a layer of aluminum hydrate, which greatly impedes the flow of the current.

Wehnelt's Rectifier for Alternating Currents.—This is a vacuum tube in which the cathode is made of platinum, gas-carbon, or tantalum, and consequently does not melt when heated to incandescence. The cathode is coated with a metallic oxid. The rarefied gas offers very little resistance to the passage of a current in one direction, but if the current is reversed, so as to make the electrode coated with oxid the anode instead of the cathode, the current is almost completely arrested. The effect is supposed to be due to ionization of the rarefied gas in the tube by the incandescent metallic oxid.

The Mercury Dip Interrupter (Fig. 450).—One of the wires carrying the primary current leads into the bottom of a glass vessel containing a certain amount of liquid metallic mercury. The other wire is connected with a vertical metal rod which is moved up and down by a small electric motor and alternately dips into and is withdrawn from contact with the mercury. The contact is thus made and broken and the alcohol which covers the surface of the mercury prevents the formation of an arc. The interruptions are of good character and may be regulated as to rapidity by varying the speed of the motor.

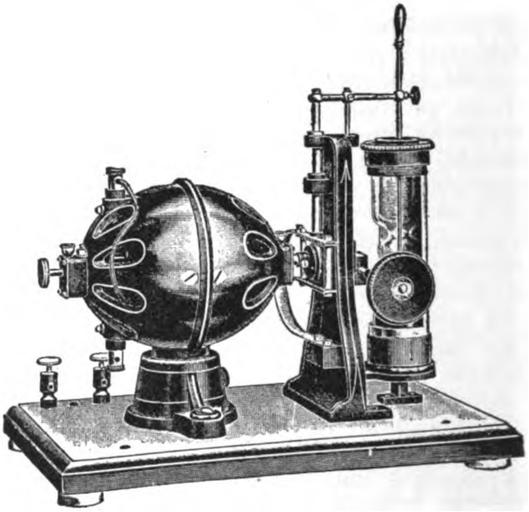

Fig. 450.—Mercury dip interrupter.

The Mercury Jet Interrupter (Fig. 451).—One of the primary wires terminates in the liquid mercury, the other in a series of metallic sections separated by insulated spaces which form a horizontal belt lining the inner wall of the alcohol reservoir a certain distance above the surface of the mercury. An electric motor causes the revolution of a vertical shaft which dips into the metallic mercury. By centrifugal force the mercury is drawn up into a tube in this shaft and thrown out through

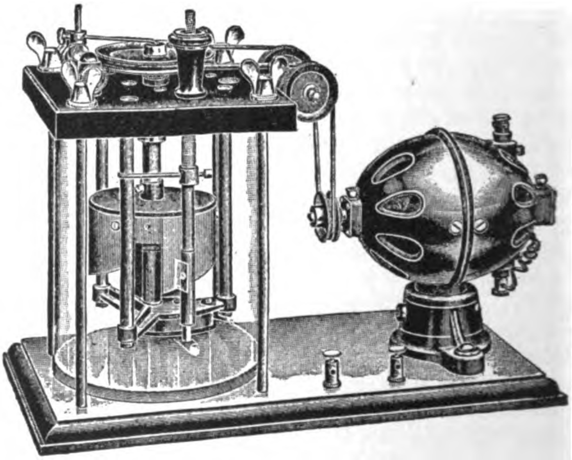

Fig. 451.—Mercury jet interrupter.

a horizontal nozzle. The jet of mercury passes through the alcohol to come in contact with one of the metal segments and complete the metallic circuit. At the next part of the revolution the mercury jet is directed against one of the insulated spaces and no electric current flows. The interruptions may be made faster or slower by varying the speed of the motor and arcing is prevented by submersion below the surface of the alcohol.

Ropiquet's Mercury Turbine Interrupter.—The new features of this interrupter[1] are that the jet of mercury does not form one of the electrodes, but simply a conducting bridge between them, and that the contact is broken partly by the interposition of a non-conducting barrier. The complete apparatus is shown in Fig. 452. There is a small electric motor which is run by the 110- or 220-volt direct current and the speed of which can be regulated by means of a rheostat. A leather belt connects this motor with the vertical axis of the interrupter and causes it to revolve. Two conducting wires, one from the wall-socket of the 110- or 220-volt electric-light circuit and the other leading to one terminal of the primary of an induction-coil, are fastened to vertical metal rods which can be raised or lowered by insulated screws. These pass down through about 2 quarts of alcohol, but do not reach the level of the 8 pounds of mercury in the bottom of the interrupter. At their lower extremity these rods expand into triangular surfaces, large above and pointed below. The lower part of the revolving axis is hollow and contains a pump, on the principle of the turbine or a sort of cork-screw motion, which draws the mercury up through the hollow shaft of the vertical axis and out through two horizontal tubes. These two tubes also revolve with the vertical axis and centrifugal force is added to that produced by the pump. Two jets of mercury are thrown out through the alcohol in a horizontal direction and as the axis revolves these jets also make complete revolutions. In a certain position the two jets impinge upon the two metal electrodes and form a complete conducting path of metallic mercury between the two electrodes. As the jets continue to revolve, they pass the point at which they are in contact with the metal electrodes and the circuit is thereby broken, but besides this they strike against hard-rubber or other insulating barriers. These are placed obliquely and as the mercury strikes one of them it, of course, is prevented from going out as far as the metal electrode. The breaking of the electric contact is rendered much more complete and sudden than when the sole dependence is placed upon the circular sweep of the mercury jet. In the latter case the break spark is of considerable volume because the mercury does not get far enough away from the metal electrode for quite an appreciable length of time and there is also a perfectly straight path between them. With this new improvement the mercury jet is instantly stopped at a considerable distance from the metallic electrode and the formation of an arc is

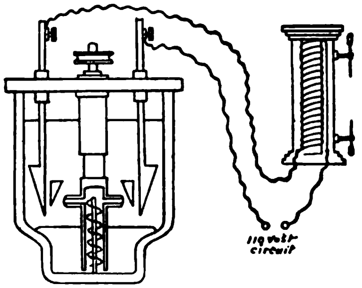

Fig. 452.—Ropiquet's mercury turbine interrupter.

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[1] Published March 10, 1906, Archives d'electricite Medicale, Bordeaux, France.

further prevented by the oblique direction of the hard-rubber barrier. As the mercury jet passes over this surface the break spark would have to turn quite an acute angle in order to pass from the electrode to the mercury. The rupture is so complete that no condenser is required to suppress the break spark for safety to the apparatus or for securing a good quality of induced secondary current. This interrupter also enables one to dispense with a rheostat or a volt controller, because the strength of the current can be regulated from 1 to 15 amperes by adjustment of the interrupter alone. The way in which the current strength is increased is by lowering the metal electrodes and thus presenting a wider surface for the mercury jet to sweep across and increasing the fraction of each revolution, during which the current flows. The average strength of the current is what is meant when we say that a primary current of a certain number of amperes is used. This is determined by the proportion between the time that the current is flowing and the time that it is interrupted. There is a very small total resistance in the circuit, 1 or 2 ohms resistance from friction in the primary wire and not much more additional resistance from self-induction and practically no resistance in passing through the conducting jet of mercury in the interrupter. At any time that the current is flowing it may encounter a total resistance of only 2, 3, or 4 ohms, and, according to Ohm's law, the current strength would be from 50 to 20 amperes with 100 volts or 100 to 40 amperes with 200 volts. The strength of the current in amperes is equal to the number of volts divided by the resistance. Such a strength may actually flow for fractional periods of time during the passage of the current through this interrupter, but the periods of time during which there is no current at all brings the average down to a much smaller number of amperes. This is regulated at somewhere between 1 and 15 amperes for most therapeutic purposes. There is no possibility of the interrupter stopping in such a position as to produce a stationary mercury bridge across the space between the metallic electrodes and permit a continuous flow of the current which, of course, would be destructive because of its strength. The mercury bridge is only formed when the axis is in rapid rotation; when the shaft is stationary there is no turbine pump force at work to raise the mercury in the hollow axis and no centrifugal force to impel it out horizontally and cause it to strike against the two electrodes. The amperemeter which measures the strength of the primary current indicates the average number of amperes. Even if the instrument were made with a needle which would pass back and forth from the zero to the 50 or 100 ampere mark on the dial scores of times a second it would be useless. The eye could not follow its motions, and even if it could we should not obtain the information that we require.

An obturator may be adjusted to prevent the two opposite mercury jets from striking the metal electrodes in one position while they still continue to do so when in the opposite position. This permits of the passage of the current only once for each complete revolution of the axis instead of twice, as is the case when the obturator is not used. Each tiny fraction of a second that the current flows produces practically the same effect upon an *x*-ray tube, whether this occurs once or twice for each revolution of the axis. The visible effect and the fluoroscopic image will be about the same in both cases. The obturator and the reduced rate of current flow may be used for fluoroscopic examinations and will avoid wear and tear upon the x-ray tube and reduce by one-half the effect upon the patient. It will be found best to dispense with the obturator and thus secure the double rate of current flow for making radiographs, the same quantity of radiation being produced in half the time. Either the single or the double rate may be used for x-ray treatments, due allowance being made for the difference in the amount of radiance. This may be made clearer by an example in ordinary photography. If we have a 100-candle-power arc light which is only turned on for one-sixth of every small fraction of a second, it will illuminate the interior of the room to the full 1000-candle-power extent each time, and the persistence of the effect upon the retina of the eye may enable one to see objects practically the same as if there were two such periods of illumination for one-sixth of the time or a total of one-third of each small fraction of a second. The effect registered upon a photographic plate or its physiologic effect upon plants or animals would be twice as great with the double as with the single rate of exposure.

Somewhat similar variations in the current may be obtained with the Wehnelt interrupter by having different sizes of platinum rods and means for regulating the length of the platinum rod exposed; by using a variety of electrolytes of greater or less conductivity and by the use of a rheostat.

Ropiquet's interrupter supplies the desiderata of a mathematic regulation of the average strength of the current; a uniform strength of current while the contact is made and a very sharp and perfect break; the regulation of the number of contacts per second and of the relation in time between the duration of each contact and the interval between them.

Either a rheostat or a volt controller may be used with this interrupter and will supply useful though not essential modifications of the current. It will enable us, for instance, to modify the strength of the current without changing the duration of each contact, as is done when the strength is regulated by adjustment of the electrodes in the interrupter itself.

Care of Mercury Interrupters.—There is a small amount of sparking as the contact is broken in all these mechanic interrupters, and this corrodes the metal surfaces and the alcohol becomes muddy and has to be changed. A scum which forms upon the surface of the mercury must be washed off occasionally, so that a certain amount of expert care is required at short intervals. Fortunately, the motor is not likely to get out of order frequently. The alcohol does not often take fire from the sparks at the making and breaking of the contacts because the latter are below the surface and no free oxygen is present to combine with the alcohol. But when this does happen there is danger of fire. These mechanic interrupters are excellent for x-ray and other extremely heavy electrotherapeutic work, but they are more expensive and more complicated than electrolytic interrupters.

The Commutator Type of Interrupter.—One of the best of these is the *Johnston interrupter*, made by the Westinghouse Company. It is an electric motor whose shaft dips obliquely below the surface of alcohol in a metallic reservoir, and upon this shaft is mounted a series of metal contacts alternating with insulated spaces of mica or indurated fiber. As this revolves, a stationary metal brush comes in contact first with a metal section, making the current, and then with an insulating section breaking the current. Submersion below the surface of the alcohol prevents the formation of an arc as the current is broken.

The *Contremoulin interrupter* (Fig. 453), made by Gaiffe, of Paris, is another of the commutator type. A small electric motor causes the revolution of a disk of insulating material in which are inlaid strips of metal as in Fig. 453. Four strips of metal separated by portions of the insulating substance form the rim of the disk and separate metal strips connect the opposite strips; so that there are two independent pairs of metallic conductors separated by non-conducting sections. The current passes through metallic brushes which are at opposite sides of the revolving disk and press upon its periphery. At times the brushes are pressing against the surfaces of one pair of metal strips and, of course, the current is transmitted. At other times the brushes are in contact with the insulating material and then the current ceases to flow. Then the disk revolving to another position brings the other pair of metal strips in contact with the brushes, completes the electric connection, and allows the current to flow again. The number of interruptions per second is varied according to the speed of the motor, and then again the apparatus may be made with more than two pairs of conducting strips, and this will increase the number of interruptions produced by each revolution. This is a really excellent type of interrupter for currents of any moderate strength. Its action is positive, each make and break being perfect without any ineffectual contacts, as with a vibrating interrupter, but arcing is liable to occur with the heaviest *x*-ray currents and it should be submerged in alcohol if used for that purpose.

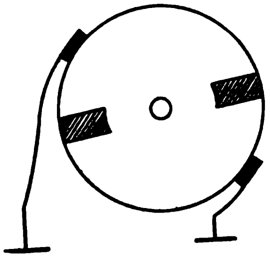

Fig. 453.—Principle of the Contremoulin interrupter.

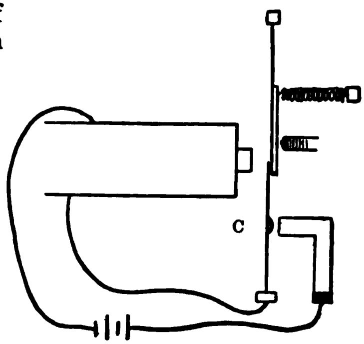

Fig. 454.—Carpentier's atonic interrupter. Contact is made and broken at C.

Carpentier's interrupter (Fig. 454) is of the *atonic* or *aperiodic* type. The hammer which is to be attracted by the magnetized iron core of the primary coil is upon a rigid stem which is drawn away from the core and held against the point of a screw by the traction of a spiral spring. In no position does the hammer or its stem transmit the current. When the current is turned on the iron core becomes an electromagnet and attracts the hammer, which, moving forward, presses against a straight spring which has been transmitting the current, but now has its end pushed away from the point of contact. This stops the current; the hammer is drawn back to its original position by the action of the spiral spring; the contact-bearing spring goes back to its position, where an electric contact is again made between a platinum surface on the spring and the platinum point of a screw placed there. The current flows again and the same interruption is produced. The limits of the usefulness of such an interrupter for *x*-ray work are an 8-inch coil with a current of 16 volts and an average of 6 or 7 amperes and 32 interruptions per second; or 4 volts and an average of 10 amperes and 3 interruptions a second. With the first speed of interruption good but not the most rapid *x*-ray work can be done, for instance, with a battery of 6 storage-cells giving 12 volts a radiograph of the pelvis can be made in six minutes. High-frequency apparatus also works well with such a current. A condenser is necessary with a coil supplied with such an interrupter. The rapidity of the interruptions is partly self-regulating; depending upon the strength of the electromagnet and hence upon the strength of the current and the amount of self-induction in the primary coil; and partly adjustable by changing the tension of the spiral spring connected with the hammer, and by turning the screw against which the hammer presses when at rest. Advancing this point makes a shorter excursion or to-and-fro path for the hammer and makes the interruptions more rapid. The adjustment of the screw which bears the point of contact is not particularly for the regulation of speed, although it may affect the speed incidentally, and the other speed adjustments may have to be altered to correct the change made by it. This screw is intended to be turned when the contacts seem to be imperfect.

The Carpentier interrupter, like all others of the vibrating type, must be used in the air, and is limited to a strength of current which will not produce an arc between the points of contact when they are separated. It cannot be submerged in any liquid. To use such an interrupter with the 110- or 220-volt current a motor generator or rotary transformer would be required giving a current of 18 volts and 8 amperes. A voltaic battery of 6 or 8 large bichromate of potash cells may be used.

A storage-battery of 6 or 8 cells would also operate an *x*-ray coil provided with a Carpentier interrupter.

A condenser is a necessity with this type of interrupter, and an adjustable resistance or rheostat affords the most convenient means of regulating the strength of the current.

Other interrupters are described at p. 802, in the section on Radiography.

REGULATION OF THE PRIMARY CURRENT

The strength of the current varies directly and the rapidity of the interruptions inversely as the size of the pin-holes in the Caldwell interrupter, and it is necessary to have a rheostat to reduce the strength of the current in cases in which the full current transmitted by the interrupter is not required.

The greater length of platinum point exposed in the Wehnelt interrupter the heavier current is transmitted. Other interrupters also regulate the current strength to a certain extent. It is always desirable, however, to have a separate regulator, called a rheostat.

The Rheostat.—Two general types of rheostat are suitable for *x*-ray apparatus. One is made of rather fine iron wire wound upon a long insulated cylinder, a rack and pinion movement changes the point of contact to different turns of the iron wire. The current in this way may be allowed to pass with scarcely any resistance or gradually the whole resistance of the 25 yards of iron wire may be turned on. This type may be called a drum rheostat. The other type consists of an insulated iron plate across the back of which are fastened 15 strips of sheet iron or of German silver, each several feet long, but crimped so as to be fastened between binding-posts only 9 or 10 inches apart. With the insulated handle turned all the way over the contact is made between points which permit the current to pass with more or less resistance.

Rheostat Used with the Author's 12-inch Induction-coil.—The rheostat has a number of different steps. Nearest the short-circuit position or the position where no rheostat resistance is introduced there is a step with a resistance of 0.4 ohms. Following this there are three other steps of 0.4 ohms each; 2 of 0.5 ohms each; 2 of 0.7 ohms each; 2 of 1 ohm each; 2 of 1.75 ohms each, and, finally, 2 of 2 ohms each.

For radiography with a Wehnelt interrupter the author cuts out all the resistance from the rheostat; but with the Wappler mechanic interrupter he employs a rheostat resistance of about 6 ohms.

For radiotherapy 6 or 8 ohms rheostat resistance are employed with the Wehnelt interrupter and 12 or 14 with the Wappler mechanic interrupter.

The rheostat resistance required for high-frequency currents is usually 16 ohms if the Wappler mechanic interrupter is used, or 12 or 14 ohms with the Wehnelt interrupter.

Turning the handle back, the current must pass through one or more lengths of crimped iron, and is reduced in strength by the resistance encountered. The further the handle is turned in this direction the greater is the resistance and the less the strength of the current which is allowed to pass.

Either kind of rheostat, depending on the fact that iron is a poor conductor of electricity, becomes heated in consequence of the friction encountered by the current in passing through it. The greater the resistance introduced the greater the heat, but this does no harm, provided the capacity of the rheostat is not exceeded. The gridiron rheostat is made to carry the heaviest currents.

The **primary coil** is of heavy, well insulated copper wire (No. 12, B. W. S.), and is wound around a core consisting of many rods of soft iron (No. 30, B. W. S.). The iron core is about 2 inches in diameter for a 12-inch coil. It becomes a powerful electromagnet and adds very much to the amount of induction. The wire should be wound like thread on a spool, all the turns being in the same direction, but in two or three or more layers, depending on the size of the coil, and it should be provided with several binding-posts, by means of which the conducting cords may be attached in such a way as to vary the path that the current must pass through. Thus the current may be made to pass through the entire length of the wire in the primary coil as a single continuous skein, or it may pass through all the layers but one or two, or perhaps only through one layer. In a portable outfit designed by Caldwell and made by Van Houten and Ten Broeck, the variation is only from one continuous skein to four parallel skeins. All these devices produce what is known as variable self-inductance in the primary, and it will be seen later that the manipulation of this is of the greatest importance in radiography.

Self-induction from a direct or continuous current practically occurs only in coils having an iron core.

According to Albers Schoenberg, the primary coil for a 50-cm. coil, that is, one designed to give a heavy discharge across a space of 50 cm. (17 inches), should consist of six layers, giving a variation of from 160 to 1000 turns.

The vibrating interrupter of an *x*-ray coil may be placed in air compressed to 2 or 3 atmospheric pressures and this will prevent arcing, according to Januszkiewicz (Phys. Zeit., No. 12, 1906).

A **condenser** is required for an *x*-ray coil when any kind of mechanic interrupter is used. It is made up of sheets of tin-foil about 8 inches square separated by paraffin paper or mica. It is necessary that the insulation between the two sets of 50 to 100 sheets should be perfect, because otherwise the primary current would be short circuited and would flow through the condenser instead of through the primary coil. To secure this perfect insulation it is best to boil the condenser in melted paraffin until every bubble of air escapes.

The **secondary coil** is built up around a hollow cylinder of mica acting as an insulator, into which the primary coil may be slipped and which has walls from ¼ to ½ inch thick, depending upon the size of the coil. The copper wire is as fine as a hair and is all wrapped with thread. It is coated with melted paraffin as it is wound on bobbins, each of which contains thousands of turns. In the author's 8-inch portable coil there are 12 pounds of No. 34 wire. The bobbins are in the form of thin circular disks with a hole in the center. They are all strung on a mica cylinder and are separated from each other by disks of hard rubber. The number of these bobbins may vary from 8 to 80, depending upon the size of the coil and upon the labor that the manufacturer puts into it. The whole coil is sometimes kept permanently immersed in oil as an insulator, but the more usual practice is to pour melted paraffin over it, which on cooling forms one solid mass. The secondary coil terminates in two brass binding-posts to which are attached the variable spark-gaps leading to the conducting cords of the *x*-ray tube, and, what is very important, rods for determining the spark resistance of the tube.

The Sprintremeter.—This consists of two rods attached to the two poles of the coil, and if they are approximated while the *x*-ray tube is in operation the distance at which a spark will leap between them is called the sparking length of the tube and indicates its resistance to the passage of the current. This is one of the elements in determining the condition of the vacuum in the tube and its fitness for various radiographic and therapeutic purposes.

The author's office *x*-ray apparatus consists of a 12-inch coil with amperemeter on the primary wire, two Wehnelt and two modified Caldwell interrupters, a Wappler wheel interrupter, gridiron rheostat, primary coil with variable self-inductance, secondary coil with the author's adjustable spark-gaps, combined with a d'Arsonval apparatus for high-frequency currents, which is connected with the coil by simply turning two brass rods into contact with the poles of the secondary coil.

Portable *x*-ray outfits should not contain any single piece weighing more than 50 pounds. The author's own outfit for use with 110 volts direct current consists of a secondary coil measuring 8½ × 8½ × 17 inches and weighing 50 pounds, a separate primary coil with three different windings weighing 17 pounds, a Wehnelt interrupter in a box measuring

8×8×9 inches, with an additional 3 inches for its screw adjustment of the platinum point and weighing 13 pounds without the fluid, which is added at the patient's home, and a carrying case for two *x*-rays tubes and four *x*-ray plates in envelopes. This case weighs 10 pounds and measures 8½×15½×20 inches. The tubes are clamped inside and the plates may be any size up to 14×17 inches, and are in an entirely separate compartment. This carrying case was made for me by Mr. Percy Russell, of New York. The tube holder is fastened to an upright which screws into one pole of the coil. The use of the Wehnelt interrupter enables us to dispense with a rheostat and an amperemeter. Tests made at the office show that when the apparatus is set up complete with a 50-cm. heavy target Müller tube and connected with the 110-volt direct current and the point of platinum, which is of 2 mm. cross-section, is just flush with the porcelain the current is 4½ amperes, regardless of what primary winding or what degree of vacuum may be used. Each complete turn of the insulated knob which regulates the Wehnelt adds 1 mm. to the length of the platinum point exposed, and by reference to a written table the amperage of the current with various primary windings and with tubes of different degrees of vacuum may be read at a glance.

Fig. 455.—Author's portable *x*-ray outfit.

Primary winding.	Revolutions of knob of interrupter = millimeters of platinum exposed.						
	0	1	2	3	4	5	
No. 1. 90 turns.	5.	6.	11.	16.	19.	25.	Amperes of primary current.
No. 2. 180 turns.	5.	5.	7.	11.	13.	17.	
No. 3. 270 turns.	4.	4.	6.	9.	12.	14.	

This is with a 7-inch tungsten target tube with medium high vacuum.

With the same tube, but with the lowest vacuum suitable for *x*-ray work and with the same conditions as to primary winding and interrupter, the amperage is found to be about one-fifth greater than the figures given above. At a patient's house or hotel it will be found wise not to employ more than about 12 amperes for the thicker parts of the body, and 6 or 9 amperes with No. 3 winding would be excellent for radiographing the extremities, and even a weaker current would be used for treatment.

If there is no electricity in the house to which you are going the current may be supplied from an electric automobile, or the above outfit can be modified by omitting the Wehnelt interrupter and taking one or more storage-battery cells and a vibrating interrupter and condenser.

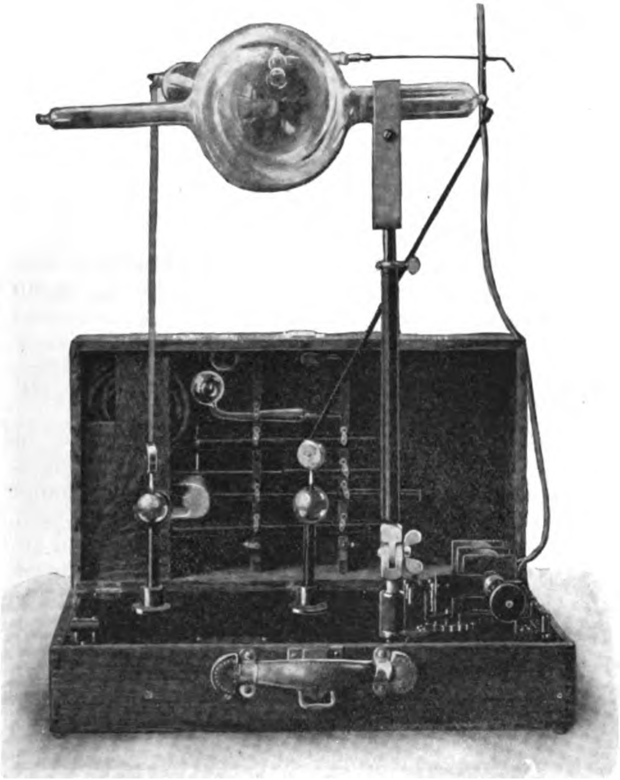

Fig. 456.—Portable *x*-ray and high-frequency apparatus of the Tesla type (Hyfrex No. 1).

The Wappler mechanic interrupter and a rheostat make a desirable substitute for the Wehnelt interrupter in a portable outfit.

Portable x-Ray Outfit of the Tesla High-frequency Type (Fig. 456).—An apparatus of the above type when closed measures 22 inches in length, 12 inches in width, and 6 inches in thickness. It weighs 38 pounds complete. The discharge is an alternating one and, therefore, does not excite an ordinary *x*-ray tube as well as if a Ruhmkorff coil were used. A high-frequency *x*-ray tube (Fig. 457), however, gives an excellent radiance, suitable for all therapeutic purposes and for the lighter forms of radiography. The apparatus is made for either the alternating or direct current.

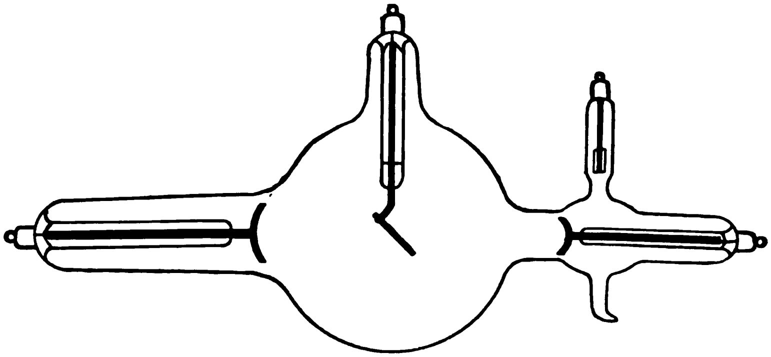

Fig. 457.—High-frequency *x*-ray tube for use when the secondary current has an alternating current.

Voltage of Different Secondary Spark Lengths.—Walter[1] reports the following voltages with alternating currents, induction spark length, in the open air:

Maximum Voltage.

10 cm.	20 cm.	30 cm.	40 cm.	50 cm.
64,000	108,000	148,000	168,000	216,000

My own observations with the Cabot direct current, high potential converter were made[2] with a gap between two loops of wire. Gaps of 1 and 2 cm. showed less than 10 kilovolts, the first graduation on my voltmeter. Gaps of 3 and 4 cm. showed about 10 kilovolts, and gaps of 5 and 6 cm. 15 and 40 kilovolts. Gaps of 7, 8, 9, and 10 cm. did not permit a spark to pass until the voltage had been raised to 64, 70, 72, and 80 kilovolts. In every case there was a drop to less than one-half the voltage during the passage of the spark. The latter phenomenon is seen also in an *x*-ray tube, where it may take a comparatively high voltage to start the current through the tube.

Power Apparently Generated in the Secondary Current.—Based upon the calculation of 100,000 volts and 2 milliamperes the power generated by an *x*-ray coil would be 500 watts, and with 100,000 volts and 15 milliamperes the apparent result would be 1500 watts. As the power of the primary or exciting current passing through the coil may be only about 500 watts and 1500 watts respectively, and since we know that nearly half of the power in the secondary is wasted in the form of inverse discharge which must be suppressed, there is apparently a greater output than intake of power. Of course this would be an impossibility, and the explanation is found in the fact that the meters indicate the maximum of the successive currents rather than their average strength.

A transformer, with a primary current of 50 amperes and 220 volts or 11 kilowatts, may yield a secondary current of 50 milliamperes and

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[1] Fortschritte auf dem Gebiete der Roentgenstrahlen, Oct. 25, 1904.
[2] May 2, 1913.

100 kilowatts of electric energy flowing through the *x*-ray tube. The direct current generator sends almost the full equivalent of the primary power through the *x*-ray tube.

Amperage of the Secondary Current.—The currents generated by the large induction-coils for *x*-ray and high-frequency currents in medical apparatus and for wireless telegraphy in commercial apparatus have very high voltage and also very appreciable amperage. A 12-inch spark means, according to some calculations, 100,000 to 300,000 volts, and the strength of the current which such a coil will send through the enormous resistance of an *x*-ray tube is from 1 to 15 milliamperes. The currents are rapidly alternating and, like most other induced currents, consist of waves, each of which has a maximum and a minimum strength. The meter shows approximately the maximum amperage without very much regard to the average strength, either of the impulses alone or of the impulses and pauses combined. Hot-wire meters indicate the current strength regardless of its alternating polarity, while electromagnetic meters (galvanometers) are of greatest value when the conditions are such that the impulses in one direction are practically suppressed.

The amperage on short-circuit is much greater, and when the poles are brought within a certain number of inches of each other the series of sparks becomes an actual flame which will readily set fire to paper. The length of the flame varies with different makes of coil, and its amperage is about equivalent to that of a continuous current of about 10 or 20 milliamperes. The maximum of each impulse of which the short-circuited secondary consists is probably very much greater than 10 or 20 milliamperes and the current will fuse a fine wire which is not perceptibly warmed by a voltaic current of that amperage. When the two poles are disconnected a spark will pass to a person's hand held near either pole and it gives quite a sharp sensation accompanied by a reflex contraction which causes the hand to be jerked away. It is not at all dangerous nor actually painful, but is rather disagreeable, like any other electric shock. The same result is obtained from either pole or from either conducting cord when the coil is actuating an *x*-ray tube, and to a less extent when actuating a high-frequency apparatus. Precautions must be taken not to allow the cords to come too near the patient or operator or any metallic object, like part of the tube-stand or table, through which a shock might be conducted. For the same reason the induction-coil and all the connections of the secondary circuit should be at an ample distance from other wires or pipes or other metallic objects. Allowing the secondary current to spark across to the 110-volt wires will burn out all the fuses along that line, even a 30-ampere fuse, and ruin the socket and its key if the wires have come from an ordinary electric-light receptacle. An undesirable and somewhat hazardous experiment consists in holding both poles of an *x*-ray coil while the current is turned on. It has been performed a sufficient number of times without any bad effects, however, to show that there is no danger of serious injury from accidental contact even with both of the wires connected with an *x*-ray coil. Such an accident should be guarded against, however, as it would probably produce more or less of a burn from an imperfect contact before the current could be turned off, in addition to the electric shock. These currents will not leap across a space of more than an inch or two from one wire to some uncharged body when the *x*-ray is in operation. This is because the *x*-ray circuit performs the function of a volt controller and the free potential at either pole of the coil or along one of the conducting cords is only half of the remainder left when the original difference in potential between the two poles of the coil has been diminished by the conductivity of the *x*-ray tube. And when an *x*-ray coil is used to actuate a high-frequency apparatus the length of spark that can be drawn from either pole of the coil, is strictly regulated by the length of the spark-gap in the high-frequency apparatus. In other words, if the two poles are brought so close together by an electric connection that they are separated by an air-gap of only ½ inch, no amount of generating power will increase their difference in potential beyond that which is required to flash across the space of ½ inch. Additional power will add to the volume of the discharge across that space, but cannot increase the difference in potential. The fact that a certain resistance is necessary to the development of a certain voltage is the reason why a spark is often required between one or both poles of a static machine and the terminals of an *x*-ray tube.

The conducting cords for *x*-ray currents should belong to one of two classes: those which frankly admit the inability of their insulation to prevent the escape of the current, and second, those which have an insulation which actually does retain the current sufficiently to permit of the cords being handled and even to come in contact with each other with impunity. The best cords of the first kind are $\frac{1}{12}$ inch in diameter, consisting of an outer insulating layer of woven silk which surrounds a bundle of 15 or 20 parallel copper threads. The silk insulation keeps the wires in a flexible cord which has no tendency to kink or tangle. These cords should be wound upon suitable spring reels for attachment to the two poles of an *x*-ray coil (Fig. 458). The cords may be drawn out to any desired distance, remain taut, and are wound up automatically when unfastened from the *x*-ray tube. These wires should be kept from contact with other conducting substances because the current will pass right through the insulation and damage the cord by burning a hole in the silk. Such an occurrence does not ruin the cord at all, because the insulation was never intended to be relied upon, and a few holes in it do not matter. Perfectly bare wires in the form of a spiral spring are cheap and convenient as to stretching out to any desired position of the tube, but they get tangled up in a most aggravating manner and are, therefore, not to be recommended. Flat steel tapes in an automatic reel are serviceable, but not so easily managed in all positions of the tube as the covered wires above described.

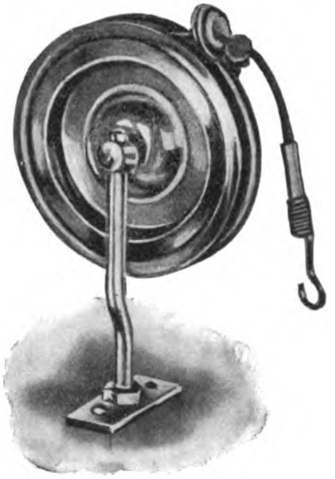

Fig. 458.—*X*-ray conductor reels.

The ordinary insulated conducting cords covered with gutta-percha and cotton or silk are not suited for high-tension currents. They are heavy and comparatively lacking in flexibility and, worst of all, they will not stand the electric strain for an instant if the two wires happen to cross or if one comes into contact with a good conductor, and they cannot be handled by the operator or be allowed to come in contact with the patient. They cannot be wound upon an automatic reel and the manipulation of the tube with reference to them becomes quite a study. Rubber and woven silk or cotton will not resist perforation by these currents, and after having once touched another wire in operation with the *x*-ray such a cord loses its insulation at that point and is destroyed for any useful purpose it might have served as an insulated wire for primary currents of 110 volts or less. These wires are clumsy and their insulation is useless for the higher voltages.

The second good class of conducting cords for *x*-ray work are those made with a sufficient coating of shellacked cloth or plaster of Paris to be impervious even to these high-voltage currents. They have an outer covering of woven silk and measure about ½ inch in diameter. They are comparatively light for cords of such large diameter and slightly flexible, enough to bend into a circle 4 inches in diameter, but should not be bent at a sharp angle for fear of breaking the insulation. When connected with an *x*-ray coil and tube in operation they may be held in the hand or may even be crossed, *i. e.*, allowed to come in contact with each other. The latter is productive of a sort of static breeze discharge between the two cords accompanied by a rustling noise and violet light. It is not destructive, but it is unwise to allow it to continue. The author used to employ these conducting cords in all cases where special treatment *x*-ray tubes were held in the hand. The small cords on the automatic reels are so convenient that they are now used for nearly all purposes, the heavily insulated cords being reserved for application of the *x*-ray in the vagina where there would be danger of the wires touching some part of the patient. This could not be allowed to happen with the lightly insulated wires, but with these others it is not annoying. If the insulation becomes broken in any way, that portion of the wire would have to be kept from contact with any conductor, but a break is not apt to occur in ordinary use.

Other methods of measuring the voltage of an *x*-ray current besides that of the spintremeter or spark distance meter are by means of an electrostatic voltmeter dependent upon the attraction of two oppositely charged wires; and of an electrometer such as is used in measuring the density of a static charge. In using the latter there is a metallic connection between one pole of the *x*-ray coil and a metal surface connected with a rod to which a pointer is hinged. Under the repulsion caused by the rod and the pointer, being both charged with the same kind of electricity, the pointer is deflected a certain distance. The graduations on the dial represent certain voltages which have been determined by the use of the electrostatic voltmeter or by the measurement of a current from a transformer whose voltage is a matter of mathematic calculation.

The voltage and amperage of the high-frequency currents from such an apparatus as the Oudin resonator actuated by an *x*-ray coil are both very great. They present a much greater apparent inconsistency between the amount of power applied to the apparatus and the amount yielded than has been noted in the case of the *x*-ray coil. The high-frequency current often has a power of 10,000 volts and 250 milliamperes, indicated by the distance of an inch, across which it will produce a continuous line of white sparks, and by a hot wire milliamperemeter.

This apparently possesses a power of 10,000 volts × 0.250 amperes = 2500 watts; while the power of the primary current in the *x*-ray coil may be only 100 volts × 5 amperes = 500 watts. The explanation is the same as in the case of other induced currents. The effect registered by different meters is rather the effect of the maximum of each successive discharge than the effect of the average power yielded by the apparatus in a certain length of time. The physical effects, like fusing fine wires and even penetrating several inches of glass by fusing a path for itself through the solid glass, are explained on the same ground. The mild character of the physiologic effect is altogether astonishing and can be explained only on the assumption that an electric discharge with alternations above 5000 to the second loses its power to excite muscular contraction and certain other physiologic effects. This applies, of course, only to the case in which the body forms a conductor for the high-frequency current produced in the body either by induction or by perfect electric connection with the electrode or electrodes. The spark from a high-frequency apparatus produces physical and physiologic effects similar to those from other sources of high-tension electricity.

The Method of Studying the Very High-tension Currents from an *x*-Ray Coil.—The most effective apparatus and one which gives a graphic representation of the strength, direction, and duration of the impulses generated by one of these extremely powerful induction-coils is called the oscilloscope.

Its construction is shown in Fig. 439. A glass tube into which wires are sealed at each end is sometimes separated into two halves by a thin transverse partition of glass or mica and sometimes has no partition. It is exhausted to the degree of vacuum usual in Geissler tubes. The leading-in wires reach to within a short distance of the septum and each terminates in a smooth rounded extremity. Such a tube may be introduced into the circuit by connecting one of its wires to a conducting cord from one pole of the *x*-ray coil and the other of its wires to a conducting cord leading to the proper terminal of the *x*-ray tube. In this arrangement the currents to the *x*-ray tube all pass through the oscilloscope. When these induced currents are passing there will be a play of violet-colored light between the ends of the leading-in wires and the intercepting diaphragm. The reflection of this light in a rapidly revolving mirror shows that it develops in a series of waves in alternate directions and separated by a pause. The general character in one of Lewis Jones' experiments (Fig. 459) was similar to that of the secondary currents in a faradic coil without an iron core. If the inverse discharge is suppressed by the proper adjustment of spark-gaps or ventril tubes or self-induction the corresponding inverse portion of the wave will be absent from the tracing. This is made by throwing the reflection of the spot of violet light from the revolving mirror upon a photographic plate. Looking at the reflection in the revolving mirror the violet light does not look like a simple spot, but like patches of light of definite shape, most probably of the character shown in Fig.

Fig. 459.—Oscilloscope observed in rapidly revolving mirror.

459, where the inverse discharge or make current in the secondary coil is above the neutral line and the direct or break current is below it. The rate of revolution of the mirror being known, we may calculate from the tracing the number of inverse and direct discharges per second. The proportion of the time occupied by each as compared with the total of each period or cycle is indicated and also the relative strength; but this method does not directly measure the voltage or amperage of these currents.

This method is applicable also to the study of high-frequency currents.

The following is quoted from the first edition of this work (1910):

"A thought has occurred to the present author that this method of studying induced currents will ultimately lead to the discovery of a perfect apparatus for the production of the *x*-ray. The ideal current, according to my view, is one which will maintain a constant difference of potential between the two poles of the *x*-ray tube instead of the rapid change from high to low potential or even to an inverse potential as produced by present methods. The ideal chart according to this view would show a uniform elevation instead of the waves in the present chart. This might occur from each individual direct discharge being lengthened by self-induction or by additional capacity in the primary or in the secondary circuit, or by increased rapidity of interruptions; and in either case it presupposes the complete suppression of the inverse discharge. The additional capacity might, for example, be a condenser, of which the two surfaces or sets of metal sheets were of enormous extent. And if such a condenser were placed in the secondary circuit the insulating plates between the two sets of armatures would have to be of great thickness and impenetrability. The only ideal generator of *x*-rays is possibly radium. The *x*-rays and other radiations seem to be sent out from radium under the influence of a constant and uniform force, just as heat and light rays or waves are sent out from a body that has been heated while hot and is kept at that temperature by a uniform source of heat. Of course, the heat is given out as vibrations, but these are millions of times a second and are like the *x*-rays from a tube in which the two electrodes were, according to the author's ideal conception, maintained at a uniform difference of potential. Let us imagine a hollow metal ball (Fig. 460) with such thin walls that it will respond to the very slightest imaginable variations in temperature acting for the shortest time, and have this heated by a gas-jet the pressure of which varies from its maximum down to zero, or which may even be replaced by a blast of cold air. Then the heat vibrations would be sent out in varying quantities, and if the variations in the source of heat were very great and rather slow there would be perceptible changes in the light and heat given out by the hot metal ball. We know that the wave lengths of the light and heat vibrations would also vary with the temperature. If the variations were very rapid and uniform they might be imperceptible and the metal sphere might seem to be giving out a uniform amount and quantity of heat and light, although in this imaginary case of a metal

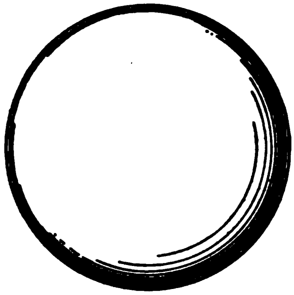

Fig. 460.—Hollow metal ball.

responding instantly to every variation in the source of heat the light was rapidly varying from its maximum quantity to zero, and its wave length was also varying, and the variations in the heat sent out were even wider. Such an apparent uniformity of heat and light emission in consequence of extreme rapidity and uniformity of variations is analogous to the best conditions we are at present able to secure in the production of the *x*-ray. At present the radiations from an *x*-ray tube are a mixture of vibrations of a great many different wave-lengths and physical and physiologic properties. With the ideal condition of a uniform and adjustable difference in potential between the two electrodes of an *x*-ray tube we should surely be able to secure a uniform production of rays and might very probably be able to produce *x*-rays all of the same wave-length and to regulate the wave-length according to the degree of penetration and other properties desired. This would correspond to a metal sphere heated to an absolutely uniform degree by an unvarying gas-jet. The radiations from a tube at the present time may be regulated so that there is a preponderance of rays of a certain wave-length, but mingled with them are others from one end of the scale to the other, and for some purposes the *x*-ray is made to pass through a sheet of some substance which arrests rays of a certain quality and transmits rays of another quality. This would not be necessary if it were possible to excite a tube so that all the rays were of the desired quality."

These pages were read by Messrs. Sewall Cabot and Joseph T. Shaw, who were seeking an improved *x*-ray generator, and after some years of experimentation they have produced a generator of a direct current of high potential and of approximately unfluctuating voltage. This is described on page 725.

Induction-coils for Very Heavy Currents.—Coils have been constructed (1907) by the Vereinigte Elektrotechnische Institute, Frankfort and Aschaffenburg, producing an abnormally powerful secondary discharge. They are said to be capable of forcing 20 to 40 milliamperes of current through a tube which is giving out No. 7 Benoist rays and through which the usual type of coil will only send ½ to 4 milliamperes. They are guaranteed to produce a chest radiograph in from one to ten seconds without an intensifying screen and are said to produce pelvis pictures in two or three seconds under favorable circumstances. These figures are for a coil in which the primary spool is 40 inches long and the distance between the secondary terminals is about 13 inches. It weighs about 150 pounds. It is very important to remember that a powerful current may be passing through the primary, as indicated by the amperemeter, and a relatively heavy current through the tube, as indicated by the milliamperemeter, and still produce no *x*-radiance at all, or so defective a radiance that only the poorest sort of picture could be made, and that would require an excessively long exposure. It is easy for the experienced eye to note the defect either with or without the fluoroscope. To determine the cause and how to remedy it are sometimes matters of great technical difficulty and it is to assist in this that the many details in this chapter have been written.

Radiography with a Single Impulse.—The current through a coil or transformer is turned on and is immediately cut off by the blowing out of a cartridge fuse. A single break discharge is thus produced which excites the *x*-ray tube for an instant. The Polyphos Co. have a patent upon an outfit in which there is so little resistance that at the single contact there is a tremendous flow of current and an extraordinary development of x-ray power. It is thus possible to take a radiograph of a crying child. Wappler, in this country, is about to manufacture a coil or transformer of this type.

Rapid Radiography with Several Parallel Wehnelt Interrupters.—This method is said to have been devised by Groedel, of Nauheim. It is applicable to an ordinary induction-coil and consists in connecting the positive electric-light wire with three large platinum points, which may be in a single large jar or in three separate ones. There would be a single large lead electrode forming the negative pole of the interrupter if a single large jar was used, or in the other case the three lead electrodes in the separate jars would all be connected with a single wire leading to the x-ray coil.

The direct electric-light current of 110 to 250 volts is used and a primary current of 60 to 90 amperes, sending a secondary current of 20 to 50 ma. through the x-ray tube. An exposure of one-fifth to one-half second produces an excellent radiograph of the chest when all the conditions are favorable. A heavy anode tube is required and a quick break switch to prevent arcing when this very strong current is turned off. An automotic circuit-breaker, cutting off the current after the proper time, is a very desirable addition to the outfit.

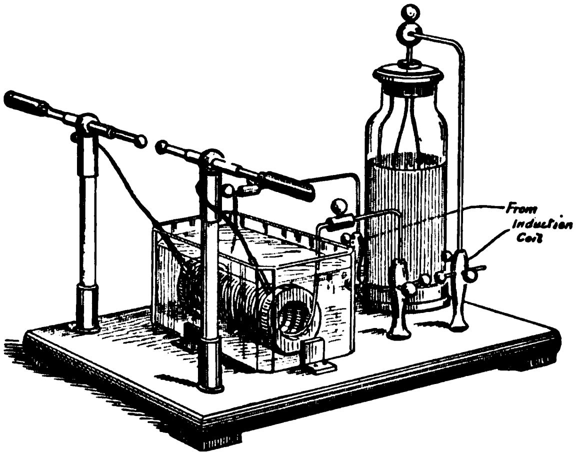

Fig. 461.—Tesla transformer wires lead to this from an induction-coil which is not shown in the cut.

The coil has to be specially adapted to this purpose, in order to secure much increase in x-ray power by the addition of one or more extra Wehnelt interrupters.

The Tesla High-frequency Coil for x-Ray Production.—Any alternating electric-light current may be connected directly with the primary of a Tesla transformer, and two small condensers highly insulated by immersion in oil have a spark-gap between the two primary armatures and their secondary armatures are connected with the primary of the spark coil. A small x-ray apparatus of this type would have about 60 turns of No. 18 gutta-percha-covered copper wire for the primary and about 300 turns of No. 30 silk-covered "magnet" wire for the secondary. The terminals of the latter are connected with the *x*-ray tube.

If an alternating electric-light current is not available the direct electric-light currents may be changed by a rotary transformer, and the alternating current thus produced may be used to actuate a Tesla coil.

An *x*-ray tube lights up with the discharge from a Tesla or high-frequency coil (Fig. 461), but it usually lacks the sharp line of demarcation and the brilliant radiance characteristic of the operation of an *x*-ray tube actuated by an induction-coil. The Ovington apparatus and the Clapp-Eastham quality coil, for instance, are excellent types of the high-frequency apparatus, but they do not give *x*-rays equal to apparatus of the same grade upon the other principle.

The reason for this is the alternating character of the discharge. Neither pole of the apparatus can be considered the negative pole, and there is as much radiation of cathode rays from the anticathode and the accessory anode as from the cathode of the *x*-ray tube. It is true that one set of impulses may be suppressed to a certain extent by ventril tubes. This means a very great waste of power as compared with the discharge from a Rhumkorff or induction-coil. The latter is so much more powerful at the moment that the primary current is broken that the Ruhmkorff coil has distinct polarity, and one pole can be considered the negative and the other the positive terminal.

An ordinary *x*-ray tube with its cathode only connected with the Oudin resonator, adjusted to give a 4-inch effluve, produces a moderately good *x*-ray. No other connection is made with the tube. The current traverses the tube not by leakage from its anode extremity, but by back-and-forth surging. The gas in the *x*-ray tube acts as a condenser.

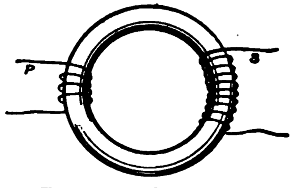

Fig. 462.—Step-up transformer: *P*, primary; *S*, secondary.

The High-tension Transformer.—A pioneer apparatus of this form for the production of the *x*-ray was introduced by Gaiffe, of Paris. To make a transformer, we take a soft iron ring (Fig. 462) and wrap a part of it it in several turns of insulated wire through which passes the primary current and wrap another or the same part of the ring with a number of turns of insulated wire in which the secondary current is to be generated. Every time the current starts or stops in the primary turns of wire a current is induced in the secondary turns of wire and the voltage of the two currents, primary and secondary, is directly proportional to the number of turns that each wire makes around the iron ring. This is a matter of every-day use in electric engineering, and if the transformer is one for changing from a low to a high voltage the appliance is called a "*step-up*" *transformer*. The appliance for changing from a high to a low voltage is called a "*step-down*" *transformer*. Transformers made for practical use in electric welding and lighting and electric power generators in factories are so perfect that the voltage is changed either up or down with the loss of only 3 per cent. of the power.

Gaiffe's transformer for *x*-ray and high frequency use must be run on an alternating current, and where only a direct current is available this must be changed to an alternating current by means of a dynamo machine known as a motor generator. The primary current is regulated by a choke coil, or inductance, or a liquid rheostat, and is measured by an amperemeter and a voltmeter. From the transformer secondary wires pass to the poles from which the connection is made with the *x*-ray tube. The strength of the current passing through the *x*-ray tube is indicated by a milliamperemeter placed directly in the circuit supplying the *x*-ray tube. The discharge from the transformer being an alternating one, two ventril tubes are introduced on the secondary circuit to take up all the discharges in one direction. A ventril tube is attached to each pole of the secondary and these two tubes are connected. They thus form a shunt circuit through which one set of discharges pass, while the other set pass through the *x*-ray tube. A ventril tube, it will be remembered, is a vacuum tube having much the same character as an *x*-ray tube, but with a simple cathode and anode and no anticathode. It is necessary that it should be provided with a regulator of its degrees of vacuum. With Gaiffe's apparatus it is necessary to have a set of condensers insulated by compressed air, and there is also a liquid resistance on each of the secondary wires. In these resistances the current has to pass between a platinum and a lead point through dilute sulphuric acid. The condensers and these liquid resistances produce uniformity of discharge by preventing self-induction in the turns of the secondary wire in the transformer from a sort of backing up action which would occur especially in connection with a high-frequency solenoid or resonator.

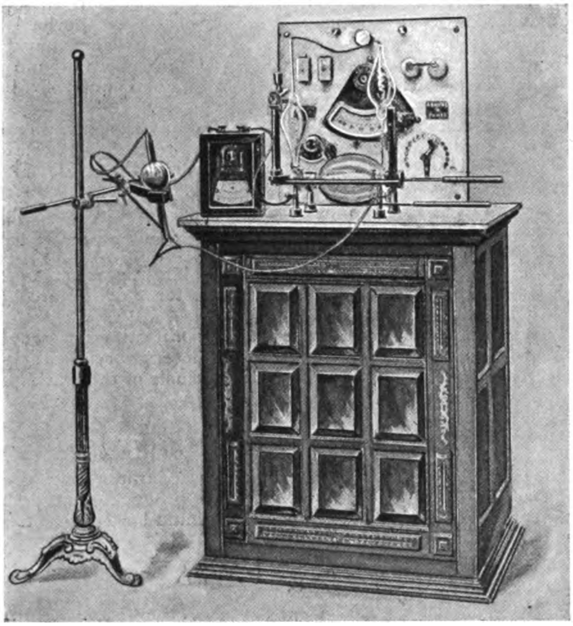

Fig. 463.—Gaiffe's transformer for *x*-ray and high-frequency currents.

The principle of the transformer for actuating an *x*-ray tube is not a new one, but this whole combination gives such uniform and powerful currents that with some European operators it has displaced the more uncertain outfits that depend upon an interrupter and an induction-coil.

Gaiffe's transformer apparatus (Figs. 463–465), for high-frequency currents and the *x*-ray, depends partly upon the use of compressed air or gas as a dielectric or insulating medium, and partly upon the introduction of resistances or inductances in the primary circuit, or derived from the secondary circuit to prevent the formation of an arc at the spark-gap.

The first is based upon the supposed fact that compressed air or other gas is a better non-conductor of effluves or disruptive discharges than gases at ordinary pressures, and that it has the advantage over solid insulation like paraffin or liquid insulation like petroleum oil, that it is perfectly homogeneous, whereas, a local defect in these others might occur. The possibility of a change occurring in the pressure of air inside the case containing the transformer produces a danger to the apparatus from a reduction in the insulation which is guarded against by a safety device. There is an orifice at a certain part of the case which is closed either by a flexible membrane or else by a piston. If a leak occurs the reduction in pressure will produce motion in the diaphragm or in the piston, and this motion actuates a quick break switch which turns off the primary current. The connection between the piston or the membrane and the switch may be a purely mechanic one, the motion being transmitted by levers and springs, or it may be an electric one, in which motion produced by the lowering of the pressure makes an electric contact, and the current so turned on operates a relay which causes the circuit breaker to act and cut off the primary current.

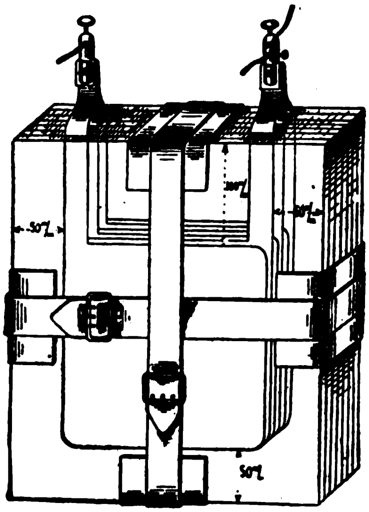

Fig. 464.—The condensers for Gaiffe's *x*-ray transformer.

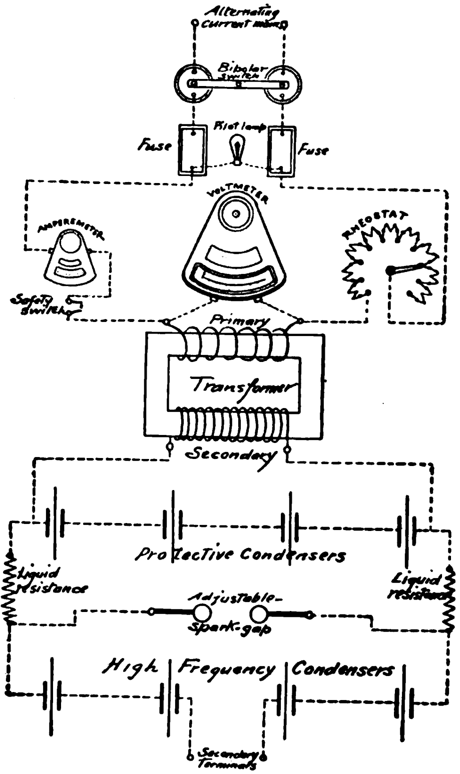

Fig. 465.—Details of Gaiffe's transformer outfit. The ventril tubes are not shown.

The suppression of the arc which tends to form at the spark-gap is a matter of experiment with different combinations of inductance. (Coils whose self-induction produce a counter-electromotive force at the proper moment to oppose the break spark, capacities whose function is like that of the condenser of an induction-coil to receive the charge generated by the increased electromotive force when the current is broken and which without a large capacity to receive it would overcharge the two poles of the spark-gap and maintain an arc.) These capacities are connected with the secondary circuit. Resistances may be placed in the primary circuit of a transformer which will have a similar effect. The magnitude of the capacities and of the inductances to be introduced varies according to the precise conditions, and in some cases of a transformer with suitable resistances the other two means may be dispensed with altogether.

Malaquin and Charbonneau have constructed a transformer giving 200,000 volts. It has two secondary circuits around a closed magnetic ring. Provided with a rectifier, it is said to excite 8 *x*-ray tubes in series.

Alternating Current Generator with High-tension Rectifier for *x*-Ray.—A transformer is used which produces an alternating current of 60,000 volts and of 1 to 5 kilowatts, depending upon the amount of primary current. This is from 10 to 50 amperes of 110-volt alternating electric-light current. This is the generator in Snook's apparatus, made by the Röntgen Manufacturing Company. If one has the direct electric-light current a motor generator is required to produce an alternating current. The current is rectified by a commutator in such a way that the top of each wave in the right direction is utilized. No ventril tube or spark-gap is required. The amount of current sent through an *x*-ray tube may be 50 ma. or more. The author has seen excellent radiographs of the chest which have been made by Dr. Leonard in an estimated time of one-half second, and pelvic radiographs made with an exposure of two seconds. Both of these were without an intensifying screen. The thorax pictures showed the diaphragm and heart with clear outlines approaching those obtained when a dead person is radiographed; they also showed the space between the heart and the diaphragm, which is usually demonstrable only by the fluoroscope.

The greatest difficulty in the use of enormously powerful currents is going to be with the *x*-ray tubes. A continuous discharge of 50 ma. or more will develop a temperature of 2000° or 3000° F. at the focus of the *x*-ray tube and fuse even iridoplatinum in a short time. The latter metal as a thick sheet riveted to a copper backing is used for the anticathode in one of the tubes made especially for these exceedingly heavy currents. Another form of anticathode is made by electroplating the platinum directly upon the copper backing. Silver-plating is useful.

Secondary Rays from a Tube Actuated by Such a Transformer.—In a personal communication to the author Dr. Leonard expressed the belief that the unidirectional character of the discharge through the *x*-ray tube results in a radiance free from secondary or vagabond rays, and that, therefore, no diaphragm would be necessary to cut off these rays and secure good definition. He said that in renal calculus cases the amount of definition was so great as even to be confusing. At the author's request Dr. Leonard has tried the author's experiment in which a silver dollar was interposed between the *x*-ray tube and a penny, so that the latter was in the shadow of the former. The penny was readily visible with the fluoroscope and in a radiograph. This was also the case when the dollar was supported upon a sheet of paper which Dr. Leonard thought would cut off secondary rays arising from the tube. His conclusion was that the image of the penny was produced by rays which had passed directly through the silver dollar. A piece of heavy sheet lead gave the same result as the silver dollar, but with more blurring, attributed to the greater diffusion of the *x*-ray by the lead. The penny in each case was 7 inches from the plate and its image showed no halation.

Fig. 466.—Kny-Scheerer "interrupterless" *x*-ray apparatus.

The author has made a number of very interesting experiments, from which he draws the conclusion that the vagabond rays are, most of them, not arrested by paper or even by heavy sole-leather, and that they arise under ordinary circumstances for all practical purposes from the glass walls of the illuminated hemisphere of the *x*-ray tube. His experiments do not enable him to say whether these secondary rays are due to cathode rays or x-rays from the focus on the anticathode striking the glass wall of the illuminated hemisphere, but his belief is that they are due chiefly to the impact of x-rays. Inverse discharge causes cathode rays to strike the glass wall of the tube and give rise to disturbing x-rays from parts outside of the illuminated hemisphere, and in this way add the blurring due to the secondary rays from the illuminated hemisphere alone. No amount of rectification of the current is going to remove the latter source of secondary rays. The most practicable ways to deal with this are by the use of a diaphragm to cut off the secondary rays and by the use of an x-ray tube with a very small active bulb communicating with a larger one acting simply as a gas container. The author's cellular radiating diaphragm gives good definition over as wide an angle as may be desired. It may be constructed to illuminate almost a hemisphere. No limitation as to the strength of current and the consequent intensity of the radiance results from the use of a diaphragm. His contact diaphragm is especially useful.

The use of an x-ray tube with only a small surface for the radiation of secondary rays while permitting of the radiation of direct rays through almost a hemisphere is also believed to be original with the author.

Kny-Scheerer "Interrupterless" x-Ray Apparatus.—The Kny-Scheerer "interrupterless" apparatus, developed from Snook's invention (Fig. 466), comprises a small stand upon which are mounted the necessary switches and rheostats and a cabinet, in which is a motor generator (U, Fig. 467), a step-up transformer (T and h a), and a high-tension commutator (b c g, etc.), which is mounted upon the same shaft as the motor generator. This high-tension rectifier is, therefore, synchronous with the alternating current furnished by the motor generator to the step-up transformer.

When a is the positive secondary pole of the step-up transformer, the positive current passes through b and the metal strip S to the terminal c, then to the anode of the x-ray tube, and from the cathode of the x-ray tube to the terminal f. From here it passes through the metal strip S_1 and g to h, the negative pole of the transformer.

During this time the positive current cannot reach the cathode of the x-ray tube because the insulated part of the right revolving disk is interposed. The insulated part of the left commutator disk is also interposed in the path from the negative pole to the anode of the x-ray tube.

At the other phase of the high-tension current both commutator disks have performed a half-revolution, so that a complete metallic path is furnished by h, which is now the positive pole, through g and S_1 and c to the anode of the x-ray tube. From the cathode of the x-ray tube the positive current passes to f and S, which is now in a line between f and b_1, from which it passes to a, which is now the negative pole of the transformer.

The current delivered to the x-ray tube is unidirectional and pulsating (Fig. 468), and is much less destructive of tubes than the alternating discharge from an ordinary induction-coil, as in Fig. 469.

The simplest type of this apparatus is the one made for use with the direct electric-light current, because the high-tension commutator is

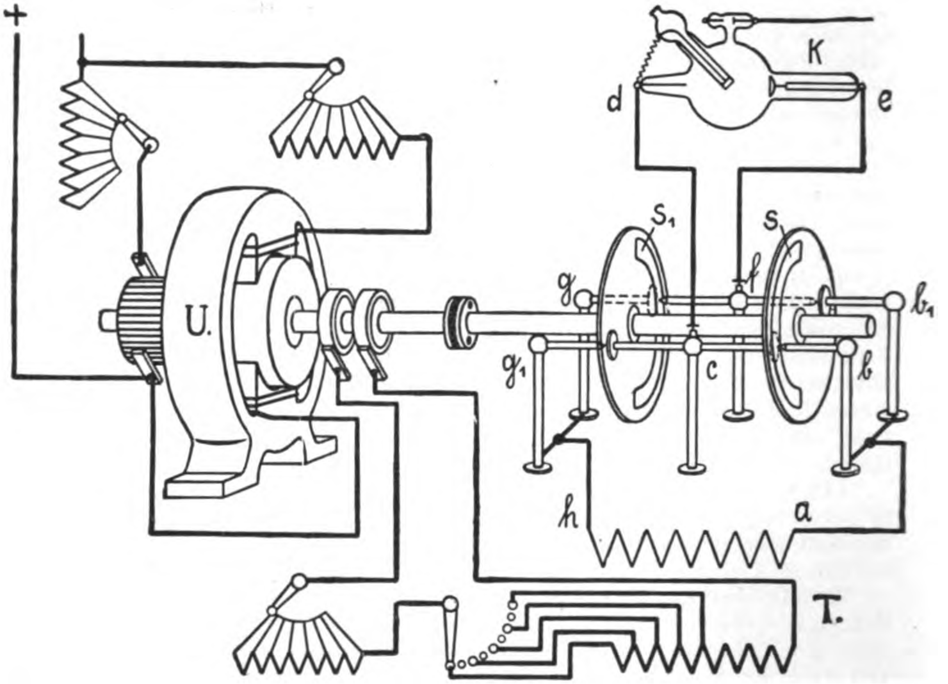

Fig. 467.—Transformer and high-tension commutator of Kny-Scheerer "interrupterless" *x*-ray apparatus.

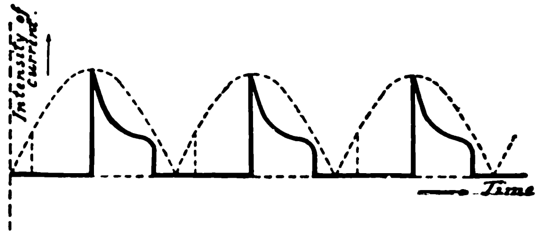

Fig. 468.—Current delivered to *x*-ray tube by transformer with high-tension commutator.

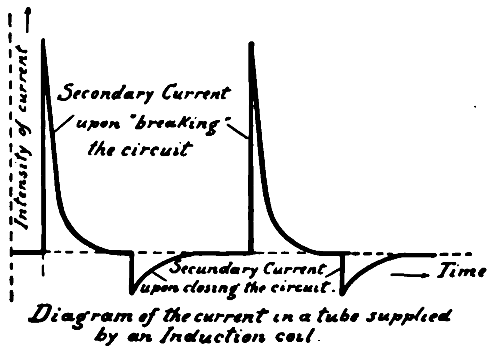

Fig. 469.—Current delivered to *x*-ray tube by ordinary induction-coil.

made absolutely synchronous with the alternating current supplied to the transformer by mounting the commutator upon the same shaft as the motor generator. The alternating electric-light current and triple and other polyphase currents could be supplied immediately to the transformer except for the difficulty of securing absolute synchronism in the separate motor which would be required to run the commutator. This synchronism will probably be attained in the future, but for the present the most reliable method for employing the alternating electric-light current or multiple phase current is to use it to run a motor generator with the high-tension commutator mounted upon its shaft.

Waite and *Bartlett* and *Wappler* are among the American manufacturers who make excellent transformers for x-ray work.

Open or Closed Core Transformers for x-Ray Work.—There is an impression that a transformer in which there is not a complete iron ring gives a better quality of x-ray for such subjects as the frontal sinus. This be should determined by the manufacturers.

A 9-inch transformer is excellent for "instantaneous" Röntgenography and for telerötgenography. The maximum capacity of such an apparatus is 4 kilowatts and the output can be regulated for the mildest radiotherapy and for exciting high-frequency apparatus. They are made up to 11 kilowatt capacity, which of course is much better.

Direct Current Motor Generator for x-Ray Work.—An apparatus of this kind was under construction by the Baker Electric Company at the publication of the first edition of the present work, and was designed to develop a continuous direct current of 50,000 volts and an energy of 4½ kilowatts. This means the use of about 50 amperes of 110-volt direct current to run the motor. Seven or eight horse-power are generated and a shock from this current will be a much more serious matter than one from an ordinary coil or static machine. Electric engineers had up to that time considered 10,000 volts the practical limit in generating direct currents. It has not been brought to perfection.

Unfluctuating, High Potential Constant Current Generator for Exciting an x-Ray Tube.—In the first edition of this work (page 663) the author expressed the opinion that neither the induction-coil or the static machine or the transformer with a high-tension rectifier, or the Grissonator with its series of impulses in the right direction, was the ideal generator for x-ray purposes, and that a generator of a constant, and, of course, unidirectional high potential current which could be regulated to any voltage would be preferable for the following reasons:

The discovery of this apparatus came about from the perusal of these paragraphs by Messrs. Cabot and Shaw, electric engineers engaged in the manufacture of high-tension apparatus for wireless telegraphy and other purposes, and Mr. Cabot, having already been at work upon a means of generating high-tension direct current for electrometallurgy, they decided to apply their invention, in the first place, to the generation of current for x-ray purposes. Their first apparatus, the heterodyne, consisted of a transformer in which an alternating current of 220 volts was stepped up to a current of many thousand volts, which was made unidirectional and practically constant by means of condensers of very great capacity, and inductances acting as choke coils for suppressing currents in the wrong direction.

This was an advance over *the Grissonator*, which gave a series of secondary currents in the right direction, but, of course, with a voltage varying from zero to a certain maximum. The Cabot heterodyne, on the contrary, furnished a constant difference of potential at the terminals of the x-ray tube. An oscilloscope in series with the x-ray tube showed a continuous luminous band in a revolving mirror instead of the series of flashes seen with any previous generator. The x-ray tube itself showed continuous luminosity in a revolving mirror, and the x-rays were approximately homogeneous, all being produced by electrons traveling at about the same speed under the impulse of an unvarying voltage. It was at this stage that the author was first visited by Messrs. Cabot and Shaw and, while this was recognized as a distinct step toward his ideal, it seemed to him that too much power was wasted, and that the correlation of the various capacities and inductances was a complicated matter, and probably not subject to accurate regulation for the different voltages and amperages required for all radiographic and treatment work.

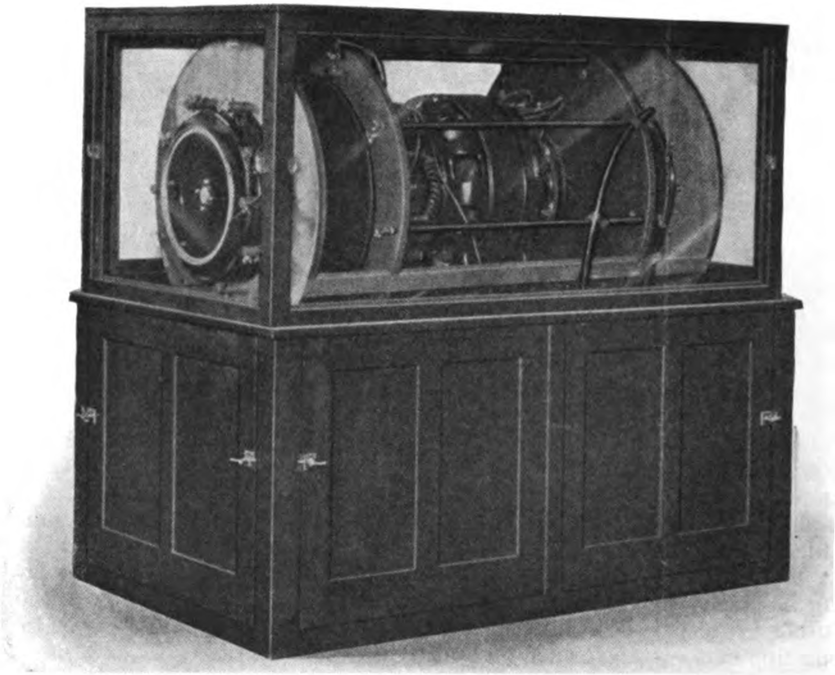

Fig. 470.—Cabot high-potential direct current converter. Delivers unfluctuating, high-potential direct current from direct or alternating current source (Electric Conversion Co., Brookline, Mass.).

Visible in the glass case is a low voltage triple-phase generator, the current from which is stepped up by three transformers, one for each phase, concealed in the base. The high-tension triple-phase current reaches the x-ray terminals through a commutator visible in the glass case.

In another glass case on top the author has a high-tension interrupter and condenser, by means of which the current is caused to flow through the tube only half or only one-tenth of the time. This is for use in fluoroscopy and radiotherapy.

The final development is the *Cabot high-potential constant voltage generator*, which requires the use of no condensers or choke coils, and transforms a direct current of 220 volts into a continuous direct current of from 10,000 to 140,000 volts, with the loss of about 1 or 2 per cent. of energy. This is accomplished without the use of condensers or inductive resistances. The 220-volts direct current operates a rotary transformer, producing triple-phase currents. These pass through the primary of a set of three transformers, connected in such a way as practically to form a Gramme's ring, and if the same strength of triple-phase current is used, of course the secondary winding at opposite ends of any diameter shows a certain difference in potential equal to that of any other opposite points. If the current were taken from any two fixed points of the secondary winding it would be a triple-phase current, which is only a special type of alternating current; but collecting this secondary current from portions by brushes which advance at the same rate as the variation in the current secures an unfluctuating secondary current. The voltage is so

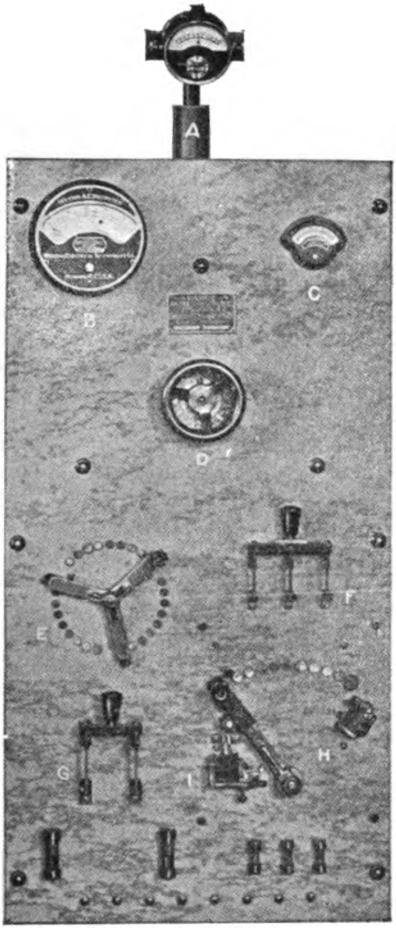

Fig. 471.—Control panel for Cabot high potential direct current converter: A, Milliameter; B, kilovoltmeter; C, primary ammeter; E, quality (ratio of transformation) lever; D, quantity (resistance regulator) lever; F, operating switch; G, main current switch; H, starting box; I, automatic overload circuit breaker. The time switch is not shown. It may be set for exposures of from one-thirty-second to one second (Electric Conversion Co., Brookline, Mass.).

high that the brushes are applied at the outside instead of near the axle, as in ordinary dynamos.

While it is equivalent to a Gramme's ring, the transformer looks more like three ordinary "step-up" transformers. The primary is in many different sections, so that any desired ratio of transformation and, consequently, any voltage may be secured. There is a rheostat to regulate the amperage of the primary current, and consequently that of the secondary current, but, of course, with a certain adjustment of the apparatus the voltage attained will be higher the greater the degree of vacuum in the tube, and the number of milliamperes passing through the tube will be correspondingly less.

Generally speaking, with an unfluctuating voltage, each 10,000 volts, corresponds to 1 degree Benoist, so that 90,000 volts indicate x-ray of about No. 9 Benoist, and the greater the number of milliamperes sent through the tube at this voltage the more quickly a radiograph will be produced or a given therapeutic effect obtained. Cabot's experiments show that with this voltage an exposure of 3400 milliampere seconds at 10 inches from the skin equal 1 Sabouraud-Noire dose. According to this estimate, if the anticathode were 10 inches from the skin and there were 34 milliamperes passing through the x-ray tube, an exposure, or a series of exposures, amounting in all to one hundred seconds, would produce a Sabouraud dose. And, again, if there were 3.4 milliamperes passing through the tube at the same voltage, representing the same degree of vacuum and the same quality of x-ray, an exposure of one thousand seconds at 10 inches from the anticathode to the skin would produce a Sabouraud dose of 5½ Holzknecht units.

Currents sent through the x-ray tube by such a generator must be prevented from undergoing oscillations analogous to those shown by the 110-volts direct current when supplied to an electric arc with a condenser, and known as the singing arc, page 618. Oscillation stoppers are, therefore, provided, which consist of spirals of fine wire wound over hollow cardboard cylinders. One of these is in circuit at each secondary terminal. An x-ray tube, with the proper degree of vacuum, excited by this apparatus, shows no inverse discharge at all in the oscilloscope, and no spark-gaps or ventril tubes are required for radiography or Röntgenotherapy. But a tube with too high a degree of vacuum shows rings indicative of inverse discharge, and this is confirmed by the oscilloscope.

The apparatus consists of several different parts. At the bottom there is the transformer, or rather there are three transformers for producing the high-potential current from the triple-phase primary current. This section may be enclosed in wood and requires no attention. The section above this contains a motor generator of triple-phase currents, having hard-rubber revolving disks mounted upon its axle, and pressing against the outer edge of each disk are metal springs acting as collecting brushes for the high-tension current. This part of the apparatus had better be enclosed in glass, so that one may see that these contacts are all right. There are two oil-wells, which should be kept full to lubricate the bearings of this motor generator.

A number of fuses and an automatic circuit-breaker protect the apparatus from too heavy currents.

Above this there is the *fluoroscopic attachment,* by means of which the high-tension current may be made to flow through the x-ray tube one-half or only one-tenth the time. This is useful for treatment and fluoroscopy, because it enables one to employ for example a secondary current of 57 or 60 kilovolts with about 2 milliamperes. There is the same degree of vacuum in the tube, and the same penetration is produced as with several times that number of milliamperes without this accessory, and the patient may be exposed for a much longer time without an over-effect.

Radiographic Exposures with the Cabot High-potential Direct Current Generator.—Turning the rheostat to a point where only 3 or 4 buttons of the resistance are still in series, and adjusting the ratio of transformation to produce 90,000 volts, an exposure of one-fourth second will produce a radiograph of the stomach and intestines with intensifying screen and radiographs of the hands without a screen. A tungsten target tube will stand a number of these exposures at intervals of a second.

Turning the rheostat to a point where only one-fourth of the entire resistance is in circuit, and adjusting the ratio of transformation for 60,000 volts, an exposure of about two seconds is suitable for screen radiographs through the body and about fifteen seconds without an intensifying screen. The same intensity will make radiographs of the extremities in two to seven and one-half seconds without a screen. The longer and weaker exposures have more effect upon the vacuum in the tube, and require a change of tube from overheating sooner than the short, strong exposures which produce an equal effect upon the photographic plate.

These two strengths of current are sufficient for practical purposes in radiography.

The *tube is regulated beforehand* with a low-tension current, until it transmits a current of 5 ma. or a little less with a pressure of about 40,000 volts.

For *Röntgenotherapy* 60,000 volt ratio is excellent, and for many cases either all the rheostat resistance may be used or about nine-tenths of it. Current values of 57,000 volts and 4 ma. correspond to about 6 Benoist and $\frac{1}{40}$ Tousey, producing a mild erythema dose of 5 H. in about forty minutes at a distance of 13½ inches from the anticathode to the skin.

A new tube will commonly light up at a tension of 20 kilovolts and pass a few milliamperes. After a little use it may require 40,000 volts and pass 5 ma. The tube in the first condition will pass perhaps 200 ma. if sufficient power is turned on to maintain a tension of 90 kilovolts at the tube terminals, while in the second condition a voltage of 90,000 will send perhaps only about 30 ma. through the tube.

A tube which has been used a number of times requires a higher and higher voltage to light up and, unless the vacuum is regulated, will eventually reach the crank stage, where 100,000 volts may be required to break down the resistance of the tube, and where, with an unfluctuating voltage generator, a great rush of current may take place with an undesirable effect upon the tube. The moral is to test the condition of the tube with small current values and use the regulator rather than extremely high voltages for overcoming crankiness.

The time of exposure with any of these voltages will be shorter the greater the number of milliamperes passing through the tube. The best current with medium and high voltages is 20 to 50 milliamperes.

Within reasonable limits it may be said that with any particular voltage or penetration factor the same number of milliampere seconds will produce the same radiographic result.

Cabot's Table of Voltages to be Maintained on Tube Terminals.

30 to 35 kv.	For great contrast in tissue details of hand or chest of thin subjects.
35 to 40 kv.	For great contrast in general work and not too thick regions.
40 to 45 kv.	For bone work where thickness of tissue is under 2 inches, for chest work on 100-pound subjects, and for general tissue detail using an intensifying screen.
45 to 50 kv.	Suitable for bone work on the extremities and chest work on 150-pound subjects.
50 to 60 kv.	Best for kidney work on light subjects. May be used for bismuth work on light subjects. Good for general bone work on the extremities.
60 to 70 kv.	Same as above with increasingly heavy subjects.
70 to 80 kv.	Only suitable for hip, frontal sinus, all bismuth work unless contrast between details is unnecessary.

Examples of Radiographic Exposures with an Unfluctuating Voltage.—A small child's hand may be radiographed with 30 kv., the thymus gland with 40 kv.; a thin adult foot with 45 kv. and 50 ma. exposure, three seconds at 28 inches.; a large 180-pound woman's abdomen with 68 kv., 40 ma., and five or six seconds. Bismuth exposures are made with 70 kv., 50 ma., an intensifying screen, and an exposure of one second or less, depending upon the size of the person. A very thick adult hip requires 80,000 volts.

The "fluoroscopic attachment," by means of which the current passes through the *x*-ray tube only one-tenth of the total time of exposure, accomplishes much more than the mere attenuation of the radiance. It makes it possible to decidedly increase the voltage, and, consequently, the penetration, without increasing the milliamperage or the total *x*-radiance to which the patient is exposed in the course of a treatment or a fluoroscopic examination.

The tube in a certain condition may transmit 5 ma. with a voltage of 40,000 and an all-time current, and show current factors of 2 ma. and 54 kilovolts with one-tenth time current. This means an increase of almost one-half in penetration and deep effect in radiotherapy and safety in fluoroscopy.

Sabouraud Dose of About 5½ H. with the Cabot Transformer.—Cabot and Dodd, experimenting at the Massachusetts General Hospital, found that with a penetration of 4 Benoist this standard erythema dose was applied by an exposure of 3400 milliampere seconds at a distance of 10 inches from the anticathode to the skin. For example, a current of $3\frac{4}{10}$ ma. would require an exposure of one thousand seconds, and an exposure of two thousand seconds with $1\frac{7}{10}$ ma. and five hundred seconds with $6\frac{8}{10}$ ma.

My own observations go to show that milliampere seconds do not form a reliable measurement of *x*-ray dosage, but that it is necessary to standardize the conditions as to voltage and milliamperage, so that these may be duplicated for each treatment of the same character with the same *x*-ray tube; and then, by means of a record of the effects upon patients or test exposures upon Sabouraud pastilles, or the author's method of comparing the photographic effect of the *x*-ray with that of incandescent electric-light, we may attain an accurate measurement of the power of the *x*-radiance itself.

Absorption of x-Rays of Different Degrees of Hardness by the Human Tissues.—Cabot's[1] results with an unfluctuating voltage, shown in the

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[1] Archives of the Roentgen Ray, Aug., 1911.

table below, agree with my own with both fluctuating and unfluctuating voltages, but with given readings of the Benoist radiochromometer, 1 Benoist for each 10 kilovolts.

Voltage on tube terminals. Kilovolts.	Thickness (inches) of tissue absorbing 90 per cent. of x-ray.
30	$1\frac{5}{8}$
40	$2\frac{1}{8}$
50	$2\frac{5}{8}$
60	$3\frac{1}{4}$
70	$3\frac{5}{8}$
80	$4\frac{1}{8}$
90	$4\frac{5}{8}$
100	$5\frac{1}{8}$

X-ray Tube Refusing to Transmit Current.—One important fact is that a tube which will not light up with any reasonable application of power in the form of an unfluctuating voltage may very likely light up under the impulsive discharge from an induction-coil, and immediately afterward operates nicely with the unfluctuating voltage. The possession of even a small induction-coil, and its use for such contingencies, will often save a tube from being punctured or having its vacuum reduced below a useful limit in the effort to pass a current of unfluctuating voltage through it. These remarks apply also to the use of the ordinary spark regulator for lowering the vacuum in the tube; it is sometimes difficult to send an unfluctuating voltage current through the regulator of a cranky tube.

It is not to be supposed, however, that such troubles are entirely avoided by the mere use of an induction-coil or of a transformer giving an impulsive current. There comes a time with every tube when a further attempt to send a current of any kind through it will result in ruin. The tube should not be forced, but sent to the maker to have a new regulator applied and re-exhausted.

THE TYPE OF TUBE

When an x-ray tube is spoken of as a 50-*cm. tube* it means that the tube is intended for use with a current strong enough to spark across a space of 50 cm., and for general radiographic work this is about the best size of tube to use. A tube of 25-cm. rating is about the smallest useful size, and one as large as 100 cm. is to be considered as a curiosity. Recently tubes have been designated as 7-inch bulbs if their diameter is 7 inches, and this is the most useful size. The bulb of a 50-cm. tube is about 6 inches in diameter and the distance from the cathode to the anticathode is about 3 inches, and usually the anode and anticathode are connected by a wire outside the tube, so that the anticathode is also an anode. The resistance to the passage of the current through the tube is very slight when the vacuum is low and almost any strength of current may be sent through it, but, of course, not long enough to overheat the tube. When the vacuum is medium, however, the resistance is such that if a current of more than a suitable strength is turned on only a portion of the current can be carried across by the cathode stream and the rest will spark across the air-space between the positive and negative tips of the tube with very great danger of puncturing the tube. This is the way that most punctures occur, the spark passing perhaps from the negative tip toward the anticathode, penetrating the glass in its attempt to effect the discharge along the shortest path. Of course, other punctures occur from allowing one of the conducting cords to hang too near the bulb, and it is partly to avoid this possibility that the various points of an *x*-ray tube are made so long. A tube in which the vacuum is very high would, of course, be sure to puncture if a powerful current were turned on. With any suitable degree of vacuum a 50-cm. tube will transmit the discharge from any of the coils or static machines ordinarily used for *x*-ray work, but, of course, a 25-cm. tube would not stand the full current. Some tubes are liable to become hard or develop a high degree of vacuum during the exposure, and it is often wise to have the positive and negative arms of the *x*-ray coil only a little farther apart than the spark resistance of the tube so as to act as a safety valve. If the vacuum in the tube and consequently its resistance become too high, the current will then leap across between the terminals of the coil instead of puncturing the tube. The same safety-valve arrangement is almost always a wise precaution against accident in the event of an excessive current from burning out or short circuiting some part of the rheostat. In such a case if the current can harmlessly jump across a space of 3 or 4 or even 5 or 8 inches between the arms of the coil it may prevent injury to the tube and alarm to the patient.

The most satisfactory tubes are the *bianodal*, in which the anticathode and the anode may be connected by a wire outside the bulb and really form a double anode. Such a tube does not blacken as quickly as one in which there is only one anode and this feature is especially valuable while the tube is being exhausted on the air-pump. It must be remembered that an *x*-ray tube consists essentially of a bulb containing a partial vacuum with a positive and a negative wire carrying to it a current of very high potential and very rapid interruptions. The current is, of course, carried from the negative to the positive pole, no matter what their relative positions may be; but as a result of the current the cathode rays start perpendicularly from every point on the surface of the cathode, which is commonly made concave so as to focus these rays upon a metal disk called the anticathode, where their impact causes the vibrations called the *x*-ray. It is not necessary that the anticathode should be connected in any way with the electric current. In fact, in some tubes used especially for treatment there is no anticathode at all, the *x*-ray originating from the impact of the cathode stream upon the glass wall of the tube. This was originally the case in all *x*-ray tubes. The essential functions of the target are so distinct from those of the anode, which is merely the positive terminal, that it is always preferable to call it the anticathode. In some tubes it forms also the only anode, and in others it may be used jointly with another anode, or may be used as the only anode, or may be entirely disconnected from the electric wires. The anticathode in any case must be placed at the focus of the cathode mirror; the anode, however, may be placed at any part of the tube at a sufficient distance from the cathode. Sometimes it will be found that a new tube has quite a low vacuum and will give better results when the anode and the anticathode are disconnected and the connection made only with the anticathode. As the tube becomes harder from use it will often be found desirable to connect the anode and the anticathode. This point is of some practical importance, but it will be found not to be of use in all tubes.

PLATE 10

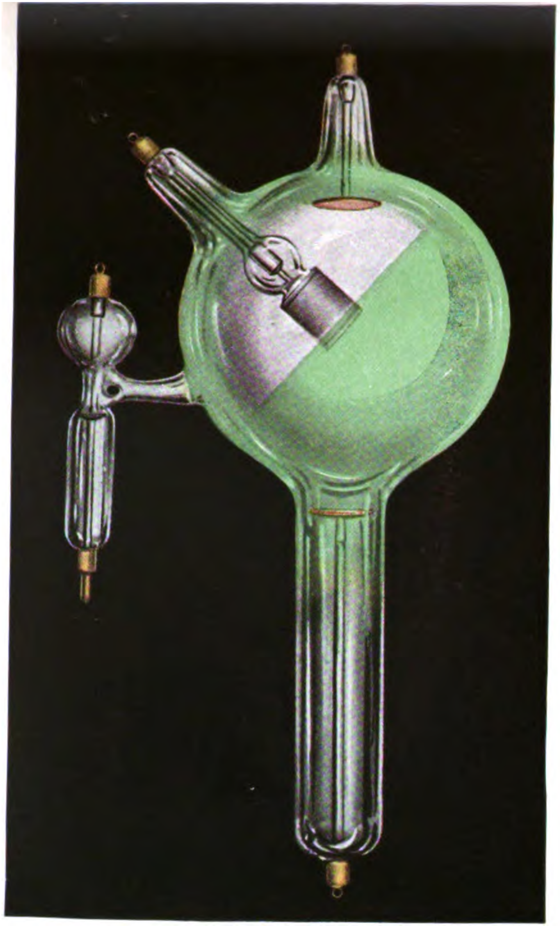

Fig. 1.—*X*-ray tube in operation. Almost ideal condition.

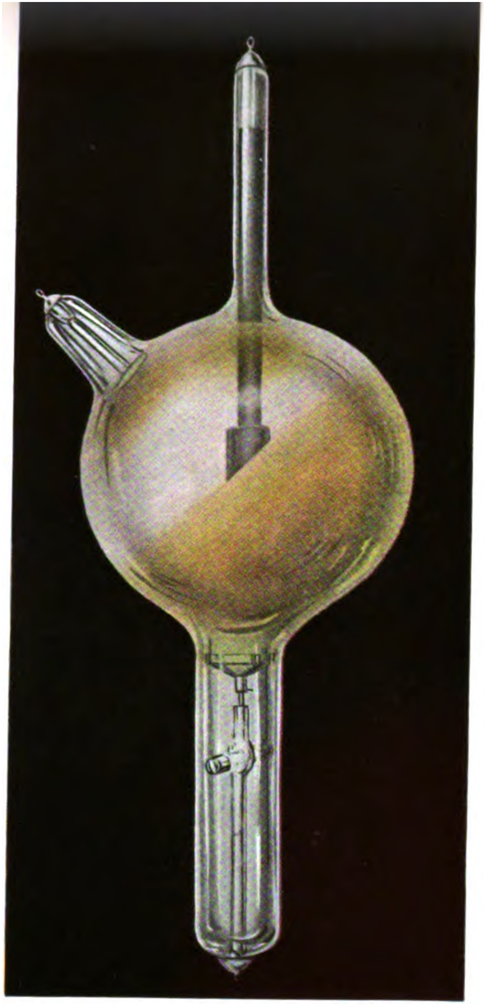

Fig. 2.—*X*-ray tube in operation. Vacuum too high. Resistance 8 inches, or 20 cm.

A very important fact, however, is that the use of the anode alone will frequently induce the proper production of the x-ray in a tube which is behaving badly. This may be due to an excess of inverse discharge. In the author's hands this has been most strikingly illustrated in the case of a heavy anode Gundelach tube of 80-cm. rating, in which no amount of regulation of the vacuum or of the self-inductance or of the interruptions or strength of the current succeeded. There was an irregular green light which almost filled the tube with flickering circles here and there and a very poor x-ray was shown by the fluoroscope. This was all immediately remedied by disconnecting the anticathode and using only the anode for the positive terminal, and the tube became sharply divided into a dark hemisphere and a hemisphere filled with brilliant steady green light with a good x-ray production. After such a tube has begun to work properly the anode and anticathode may be found to work very nicely when reconnected. As intimated above, there are several other causes and as many remedies for this troublesome condition, so that this disconnection of the anticathode is not always the thing needed.

The *line of demarcation* in an x-ray tube may be displaced forward by introducing a spark-gap in the circuit. Charbonneau,[1] who called attention to this fact, finds that the displacement is the same for any length of spark from $\frac{3}{10}$ mm. up. He finds the same amount of displacement, no matter whether the spark is on the line leading to the anode or the cathode of the tube.

Charbonneau finds that the degree of penetration is reduced 33 per cent. by any spark-gap, however short, on either line.

A perfectly continuous connection must, therefore, be made without the smallest spark-gap between the poles of the x-ray coil in order to secure the maximum field and the maximum power of radiation.

Charbonneau attributes this effect in part to the entrance of hydrogen into the x-ray tube by electric means. The hydrogen is supposed to arise from the electric decomposition of watery vapor present in the atmosphere. He puts this to practical use in reducing the vacuum in an x-ray tube which has no regulator. The connections are made in the regular way except that there is a small spark-gap on the line leading to one pole of the coil. A moderate current allowed to flow through the tube for half an hour results in a material reduction in the degree of vacuum as indicated by the spintremeter and the Benoist radiochromometer.

The "*heavy anode*" (more properly "heavy anticathode") *Gundelach tube* is an excellent one, the glass being of the very best quality for x-ray work, the osmo-regulator being first class, and the anticathode being shaped like a horse's hoof and presenting such a large mass of metal as to stand the heaviest current without fusing. (Fig. 472 shows such a tube.) There is no perfect x-ray tube, however, and one of the drawbacks of this tube is that the shadow of the anticathode is thrown in the direction in which the picture is generally taken. This is due to the fact that the anode is placed behind the anticathode, whereas, in most other tubes, the anode is in the long axis of the tube and the stem of the anticathode extends backward so that the shadow of the anticathode does not fall in front of these other tubes. Another imperfection is shared by all "heavy anode" tubes; the great mass of metal liberates so much gas that the

[1] Le Radium, Sept. 15, 1905.

tube becomes temporarily useless the moment it gets very hot. Some of the author's best radiographs have been made with a 60-cm. tube of this type, but it has seemed to him that this type of tube is a little more difficult to use than some others. If it is not in just the condition required, it requires all the skill and patience one possesses to adjust it. It has an osmo-regulator, a thin metal tube, looking like a wire, which when heated by an alcohol lamp permits hydrogen gas to pass through its pores and thus lowers the vacuum (Fig. 473). Hanging a cuff of platinum over the osmo-regulator enables one to raise the vacuum (Fig. 474). For this purpose a loose cuff of platinum is put over the platinum tube and is heated on the outside by an alcohol flame. The heat must be intense enough to make the inner as well as the outer tube red hot and consequently porous to hydrogen gas. The excess of gas in the *x*-ray tube escapes through the pores in the small red-hot platinum tube.

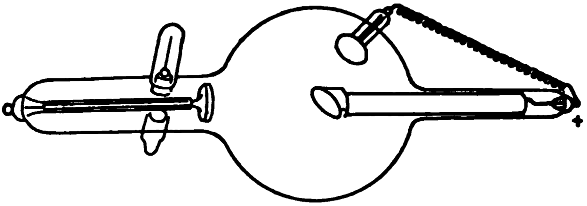

Fig. 472.—Gundelach heavy anode tube.

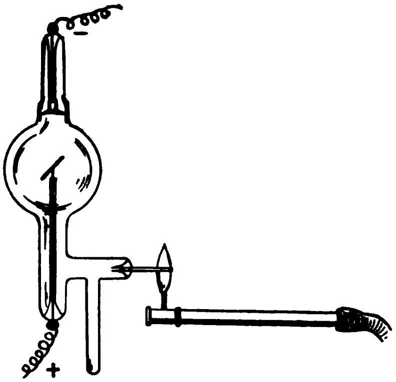

Fig. 473.—Villard's osmo-regulator lowering the degree of vacuum.

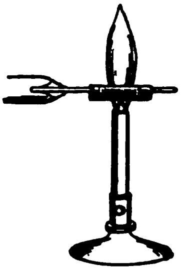

Fig. 474.—Raising the degree of vacuum.

A *special lamp* for heating an osmo-regulator has been devised by Paquelin, the inventor of the celebrated thermocautery which bears his name. By an arrangement of hand-bulb and container full of naphtha, benzene, or gasolene a jet of carburetted air may be ignited and when directed against the osmo-regulator produces the desired effect very rapidly. As in the case of the cautery, the lamp remains in full blast as long as the current of air is kept up by squeezing the hand-bulb. It is very important never to lower the vacuum to too great an extent. If the vacuum is only a little too low it can readily be brought up by running the tube for a few minutes with a reversed current. A tube in which the vacuum has become too low from overheating by the current usually returns to its original condition if simply allowed to cool, and can hardly be made to do so in any other way. The "heavy anode" Gundelach tube cools quickly and regains its original degree of vacuum very well. It seems to be better adapted for radiography than for treatment, and will stand a secondary current produced by 30 amperes of primary current. It would be the author's first choice for radiography if it were easier to keep in order. As the vacuum is very likely to fall after a long exposure it is necessary to have two tubes if difficult pictures are to be made in rapid succession.

The "*light anode*" *Gundelach tube* is one of the best of its kind and is all right for the lighter work in radiography, such as a picture of non-union after fracture of the radius and ulna. It has the osmo-regulator. This tube does not lose its degree of vacuum like the "heavy anode" tube and can be run for pictures or treatment with the anti-cathode red hot. Care must be taken not to burn a hole through the platinum disk by overheating.

Tungsten Target x-Ray Tubes.—The author's tendency is to use "heavy anode" tubes altogether for radiography and radiotherapy, and since its discovery the *tungsten target* has been exclusively adopted. Tungsten has a melting twice as high as that of platinum, and if the anti-cathode consists of about ½ pound of copper into the face of which a button of tungsten is electrically welded it is practically indestructible. Very satisfactory tubes of this kind are to be had from any of the American *x*-ray tube manufacturers. They should have a regulator for reducing the degree of vacuum.

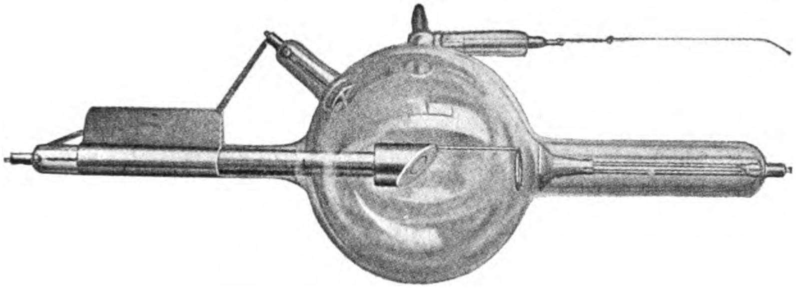

Fig. 475.—Tungsten target *x*-ray tube.

Tubes with the type of regulator found on this one may be used with the regulator so adjusted that the wire of the reducer is a measured distance from the negative tip (Fig. 476). A portion of the current will leap across this space if the resistance in the tube rises and in this way gas will be liberated and the vacuum reduced. Acting as an automatic governor this will prevent the vacuum from rising above the level determined by the distance at which the wire is placed. For radiography such an arrangement is not entirely satisfactory and fortunately we are able to dispense with it.

A small pledget of cotton moistened with water is employed in the regulator of a tube recently constructed by Dean, of London, and Berlemot, of Paris (Fig. 477).

The regulator is a separate portion of the *x*-ray tube with which a communication is established by turning a stop-cock. Watery vapor from a wet sponge in the small prolongation then enters the main bulb and lowers the degree of vacuum.

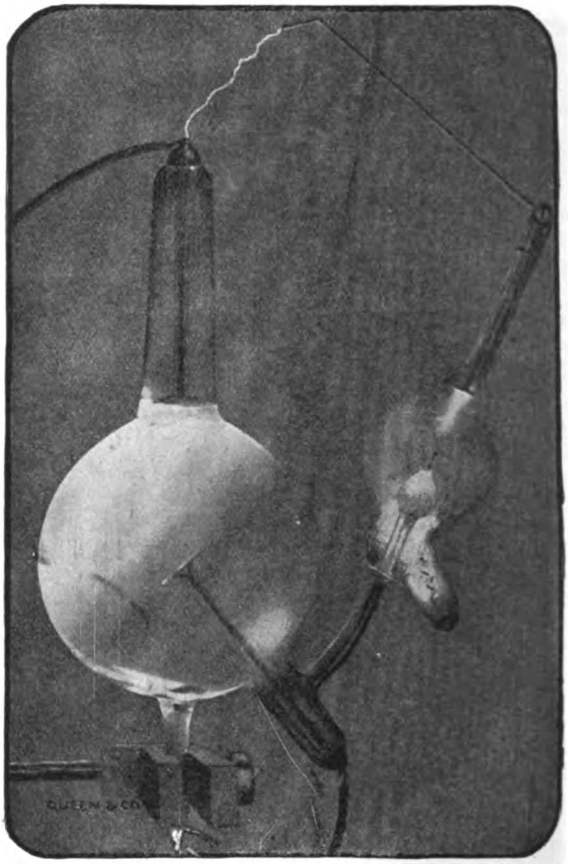

Fig. 476.—The Queen self-regulating *x*-ray tube.

Water-cooled tubes have been made by Gundelach, Müller, and others in Germany, by Machlett, of New York, and by Friedlander, of Germany and Chicago. In them there is a water-vessel (Fig. 478)

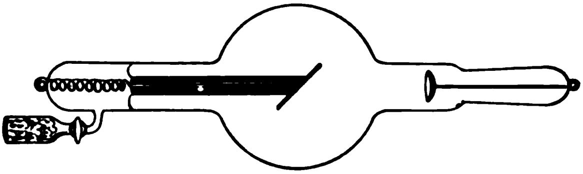

Fig. 477.—*X*-ray tube with aqueous vapor regulator.

designed more or less perfectly to prevent the anticathode from becoming too hot. In the original Friedlander water-cooled tube the water surrounds the heavy copper stem of the anticathode, but the heat reaches the water so slowly that it affords very little protection in the case of short exposures with a heavy current. This particular tube has quite a heavy target, however, and retains its vacuum quite well. Some of my best radiographic work has been done with it. The theoretically correct water-cooled tube is one in which the target forms the bottom of the water chamber. It has been found that it is better to have the disk or, rather, cup (for it forms the whole lower section of the anticathode) made of thin platinum with a backing of nickel and to have a metallic stem pass from it to the positive tip of the tube. A heavy pure platinum anticathode absorbs so much gas, like spongy platinum, that the vacuum becomes too high; and water is too poor a conductor to give the best results without a complete metallic connection. Tubes on this principle are made by all the firms mentioned above, they are expected to stand the heaviest currents, and when in working order produce beautiful pictures. They are so difficult to keep in the best condition, however, that at the present writing they seem hardly to be recommended.

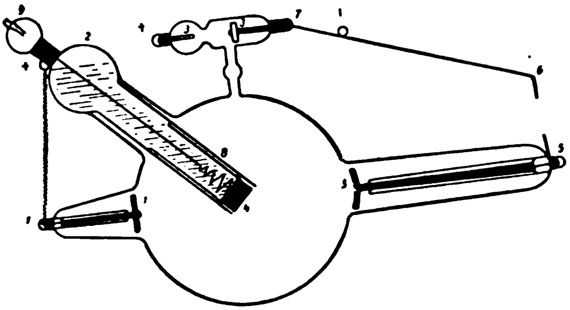

Fig. 478.—Water-cooled x-ray tube of the Müller type.

Other tubes are made in which the reduction of vacuum is produced by heating a prolongation containing potash or by passing a spark through it. In Thompson's automatic regulating tube this spark passes to the wire which leads into the prolongation containing the potash whenever the vacuum reaches a certain degree of resistance, as determined by the distance at which the wire is placed.

The *Volt-Ohm tube* has the secondary anode in a bulbous expansion of the positive prolongation of the tube. It is made with or without a regulator and the latter may be set to act automatically. It is also made with different weights of anticathode and is in every way a first-class tube.

The *bario vacuum tube* has the spark-gap leading to the regulator enclosed in hard rubber to conceal the spark and reduce the noise, and it may be set to act automatically at any degree of vacuum.

Other tubes are made with a valve arrangement by which air may be admitted and the vacuum lowered.

Still others (Friedlander) are made with an adjustable focus operated from outside the tube by means of a horseshoe magnet. A heavy current focused upon a very small spot will fuse the platinum, while this would not happen if the focus were less sharp.

The *regulating tube* of Queen & Company of Philadelphia is constructed on the same principles, but, as will be seen from the illustration, on a little different lines from the regulating tubes of Friedlander and Müller.

Tubes made with an automatic regulator, as patented by Queen & Company, may be run continuously for a long time, providing that the tube has a tendency either not to change in vacuum or to change slowly toward a higher degree of vacuum with the strength of current that is employed. The regulator is set at such a point that a spark will leap across to it if the resistance of the tube increases in consequence of the change to a higher degree of vacuum. The spark causes a generation of gas in the tube and lowers the vacuum to the proper degree. There is a certain loss of radiance during the action of the automatic regulator. This must be taken into account in estimating the exposure. Five seconds is the proper time for certain pictures, but this would not be long enough if a powerful spark were leaping across to the automatic regulator all that time.

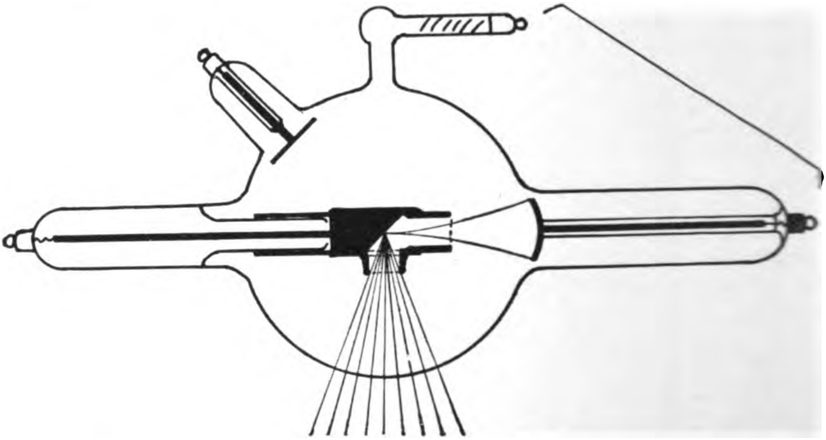

Fig. 479.—*X*-ray tube with interior filter. An abandoned model.

Helium Gas in x-Ray Tubes.—The mineral cleveite if purified over calcium and carefully dried gives out helium gas when heated.

The purest channel rays or positively charged particles are obtained in a Crookes' tube containing practically pure helium gas.

Snook has patented an *x*-ray tube in which the regulator consists of a portion of cleveite which, when heated by passing a spark through it, liberates helium and so lowers the degree of vacuum. The claim is made that such an *x*-ray tube possesses the property of giving out rays of a higher degree of penetration with the same medium resistance and other electric constants than tubes which contain other gases. The author has not been able to note very much difference, but the tube is an excellent one.

X-ray tubes with an interior filter[1] are provided with an arrangement for arresting the cathode, soft *x*-ray, and secondary rays. It allows the exit of only the direct *x*-rays which radiate from the point of impact of the cathode stream upon the anticathode (Fig. 479).

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[1] J. Rosenthal, Phys. Zeit., No. 12, 1906.

Secondary rays, however, arise from the glass wall of the tube between the points marked *x* and *x*. This model has been abandoned.

X-ray tubes have been made by Villard in 1897, and Berlemont in 1907,[1] in which an *accessory electrode* of aluminum or magnesium is used to regulate the degree of vacuum. The vacuum is lowered by connecting the accessory electrode with the anticathode. It is raised by connecting the accessory electrode with the cathode and using a weak current. Villard abandoned the idea because the absorption or liberation of molecules of gas was not abundant enough for practical purposes.

High-frequency *x*-Ray Tubes.—The tube referred to may not be entirely original with Machlett & Son of New York, but they have made it so that it gives very good results. The new feature is the construction of the accessory anode in the form of an aluminum concave mirror like the cathode, but not quite so large. Cathode rays arising from this accessory anode are focused into a funnel upon the back of the anticathode which prevents the *x*-rays produced by inverse discharge from reaching the field to be radiographed. The accessory anode may be used as the only positive terminal of the tube with the expectation that most of the *x*-ray from inverse discharge will be suppressed. This arrangement makes the tube work excellently with a direct current induction-coil which is giving a great deal of inverse discharge and also with a Tesla or high-frequency transformer which gives practically an alternating secondary current. The tube so connected may be used with a Caldwell interrupter upon the alternating electric-light circuit. The author's use of this tube has been with a 12-inch induction-coil, Wehnelt interrupter, 110-volt direct current, 18 amperes primary current, and with such a degree of vacuum that the secondary current is 8 milliamperes. Both the accessory anode and the anticathode are connected with the positive wire from the induction-coil. The exposure for a radiograph of a hand or of the teeth at a distance of 16 inches from the anticathode to the plate is five seconds or less; and for the anteroposterior radiograph of the frontal sinus at a distance of 25 inches the exposure is thirty seconds. The latter exposure is correct for the abdomen or hip, but is somewhat too long for the chest. With the tube in this condition we find that the first fifteen seconds are characterized by the presence of a steady apple-green fluorescence and a sharp dividing line in the tube, and a direct secondary current of 8 milliamperes. After the first fifteen seconds, however, the meter suddenly shows the presence of an inverse current of 10 or more milliamperes and the tube loses its sharp dividing line and much of its brilliant fluorescence. A very effective *x*-ray is still being produced, though not quite so good as at first. The presence of such an amount of *x*-ray from inverse discharge would produce a very bad effect upon the radiograph if a diaphragm and cylinder were not used to cut off all the rays except those radiating from the anticathode. Such a tube regains its original condition in a minute or two and in some cases where thirty seconds excellent radiance are required it will be found best to turn off the current at the end of fifteen seconds and then to give the remainder of the exposure later. The author does not generally have to resort to the various devices used to suppress the inverse discharge, such as spark-gaps and ventril tubes.

The anticathode in this tube is of the type of the heavy anode Gundelach tube. It is a heavy piece of copper shaped like a horse's

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[1] Exposition de la Société Française de Physique, April, 1907.

hoof and has a platinum surface. The regulator is a tube containing powdered asbestos mixed perhaps with a little potash. Preparing to take a radiograph with this tube the regulator spark is placed at a distance of 5 inches and a current of 11 amperes with a Caldwell interrupter is turned on until sparks cease to pass. Then a change is made to the Wehnelt interrupter with a current of 15 amperes until sparking ceases, and finally, to the Wehnelt interrupter with 18 amperes of primary current. The whole process of regulation takes half a minute or less and the picture is made as soon as this adjustment is finished.

It must not be imagined, however, that this or any other type of tube may be expected always to be in a condition to give the best possible results as above described. Such a tube as we are describing may be found to produce these results when it is first purchased, and if it is used only for radiography; and only with the specified strength of current and length of exposure it may remain in this condition for a great length of time. Another tube of the same type may prove disappointing at first and may gradually work into a desirable condition, while others may require to be pumped out, exhausted to different degrees of vacuum a number of times before perfection is obtained. It is no exaggeration to say that every x-ray tube of every type in the author's possession has been pumped out several times. A tube which is absolutely perfect and which has not been abused will eventually cease to work properly because the vacuum regulator becomes exhausted. A new regulator must then be introduced and as this involves opening the tube the latter must, of course, be reëxhausted. The same tubemaker being patronized right along, he, of course, knows to what degree of vacuum the exhaustion should be carried to fit the tube for the operator's apparatus and methods.

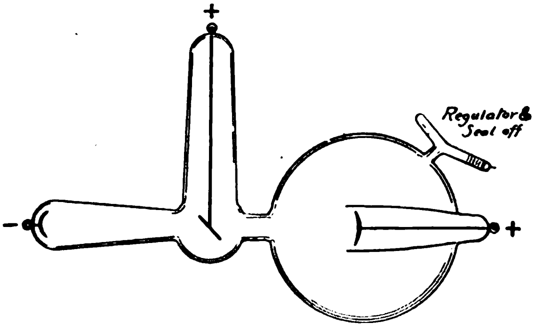

Fig. 480.—The Tousey single-focus radiographic x-ray tube.

Tubes with the same type of anticathode as this Machlett high-frequency tube are made by a number of other manufacturers in America and Europe, and generally give excellent results with quite heavy currents and short exposures.

A few tubes have been particularly described, but this is not intended as an implication that others not alluded to are inferior.

Sinclair Tousey's Tube for Radiography.—*The Single-focus Type* (Fig. 480).—The author's idea is that of a heavy anticathode situated in a small bulb an inch or two in diameter, made of soda glass transparent to the x-ray and giving as complete a hemisphere of direct radiation as any large tube, but a much smaller surface of glass to emit secondary rays. This small bulb has a number of prolongations which are made of lead glass practically opaque to x-rays, either direct or secondary. Near the extremity of one prolongation is placed the cathode for which there is not room in the small bulb because it must be placed a distance from the anticathode, bearing a certain relation to the voltage to be employed. Another prolongation from the small bulb transmits the stem of the anticathode. The uninsulated positive and negative terminals of the tube must be at such a distance from each other that there will be no sparking between them or from either of them to the opposite electrode inside the tube. The latter occurrence would cause a puncture. By another prolongation the small bulb communicates with a large bulb of lead glass. This acts as a reservoir of rarefied gas and prevents the rapid change in vacuum which would occur from the passage of a heavy current through a small tube. The vacuum regulator and the accessory anode are connected with this large bulb.

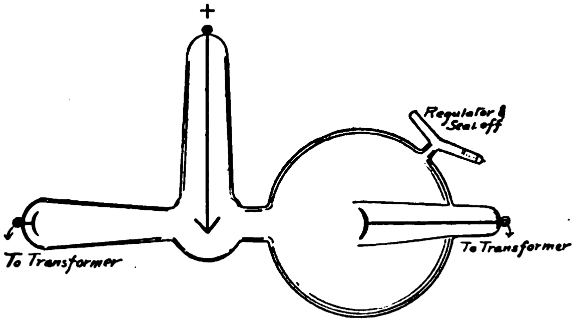

Fig. 481.—The Tousey bifocal radiographic tube.

The small bulb of soda glass permits of radiation of direct rays from the focus in every direction in front of the plane of the anticathode or almost a hemisphere of illumination. This is a great advantage over a large tube of lead glass with a small window of soda glass, which, while it may afford an equally small area for the radiation of secondary rays, gives only a very limited angle of divergence of the direct rays, and requires either that only a small picture be made or that the tube be placed at a great distance.

The single focus type is preferable in every case in which a unidirectional high-tension discharge can be obtained as with an induction-coil or a static machine or a direct current step-up rotary transformer, or an alternating current step-up transformer with some kind of a rectifier.

The Tousey Bifocal Radiographic Tube (Fig. 481).—The anticathode is wedge shaped so as to present surfaces of contact for cathode rays from two different directions, and these rays are focused quite near the angle of the wedge, so that the two points from which the direct x-ray radiate are as close together as practicable. The larger bulb and the different prolongations are made of lead glass. There are two regular cathode concave disks at opposite extremities and to these are attached the two terminals of the Tesla coil, or the step-up transformer or other source of high-tension alternating current. Neither wire is attached to the anticathode. At each impulse in one direction the concave disk electrode at one end is the cathode and concentrates a cathode stream upon the nearest surface of the anticathode, while at the same time the opposite concave electrode is the anode. At the alternate impulses in the opposite direction the other electrode becomes the cathode. Direct rays thus arise from the two surfaces of the anticathode alternately and together they illuminate considerably more than a hemisphere. The rays from the two separate foci, of course, produce separate images, but if the foci are near together the images will practically coincide. Fig. 482 rather underestimates the approach to parallelism between the direct rays from the two foci passing through any object (*a*).

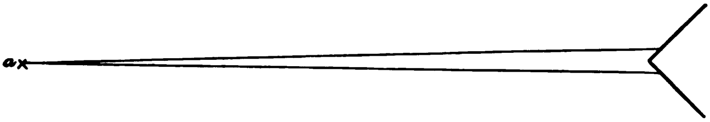

Fig. 482.—*X*-rays from the two foci in the Tousey bifocal radiographic tube are nearly parallel.

The nearer the object is to the plate the less is the blurring effect, and if the object is half-way from the plate to the anticathode its two images are only as far apart as the two foci.

Whether the tube shall be provided with accessory anodes to be connected with the two concave electrodes is a detail to be worked out by each constructor. The small bulb alone radiates secondary rays, and it is so small (only an inch or two in diameter) that these rays do not blur the image produced by the direct rays.

The *object of the Sinclair Tousey x-ray tubes for radiography* is to secure the improved definition which is obtained by the use of a diaphragm with the increased range of illumination produced by the author's radiating cellular diaphragm, but with the great additional convenience of being able to dispense with diaphragms altogether except when simple protective ones of very easy adjustment are required.

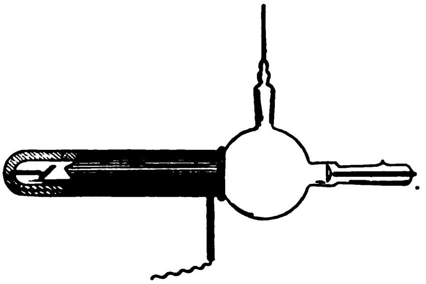

Fig. 483.—Endodiascope.

The Endodiascope.—*A Tube which May be Placed Inside the Mouth for Radiography and Radiotherapy.*—The tube (Fig. 483) has the anticathode at the tip of a prolongation. The anticathode has no electric connection, being independent of the anode, which is at a portion outside the mouth. There is an osmo-regulator. The tube is suitable for use with a 12- or 15-inch induction-coil, with a primary current of 2 amperes and a secondary current of ½ ma., and will run for fifteen minutes continuously. The radiograph (Fig. 484), poorly reproduced from a magazine, was made by Bertollotti,[1] with this tube inside the mouth and the plate outside. The exposure was two minutes.

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[1] Arch. d'electricite med., April 10, 1907.

Using this Tube for Treatment.—The same strength of current and with a degree of vacuum producing rays No. 8 or 9 Benoist and with the anticathode at a distance of 2 cm. fifteen minutes exposure equals 3 Holzknecht units. The tube is useful in treating cancer of the tongue or tonsils or simple hypertrophy of the latter. Bertollotti has cured an obstinate case of trigeminal neuralgia by application to the inferior dental nerve with this tube inside the mouth. Cancer of the larynx has been treated with benefit by holding this tube far back at the base of the tongue, the rays being directed downward.

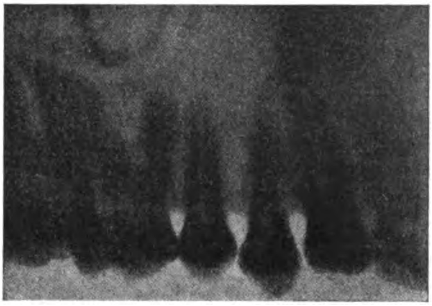

Fig. 484.—Radiograph of the teeth made with endodiascope inside the mouth and the film outside.

The Glass of Which the x-Ray Tube is Made.—The glass is usually German soda glass and gives an apple-green fluorescence when the x-ray tube is in operation.

Localizing or Safety x-Ray Tubes.—These are made in part of glass which contains a large percentage of lead, and which, while perfectly transparent and colorless with ordinary light, becomes a beautiful deep blue when the x-ray tube is in operation. This glass is very opaque to the x-ray, and all parts of the operator and the patient are shielded except opposite a window of soda glass, which forms part of the tube and permits the passage of x-rays in one direction. Many different forms of tubes like this have been made for therapeutic uses.

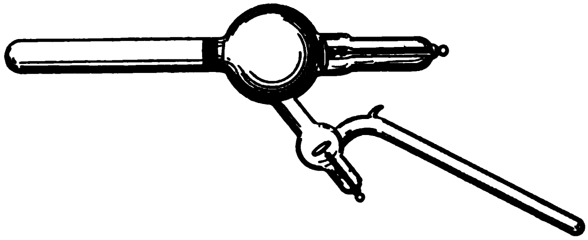

Fig. 485.—Water-jacket cancer-treatment tube for use especially in the rectum.

X-ray Tubes Without an Anticathode.—Röntgen's original x-ray tubes were made without an anticathode. The x-rays arose from the impact of the cathode rays upon the glass wall of the tube. There were two objections to this for radiography: the x-ray radiated from many different points of a large surface and hence the shadows were very vague as compared with those produced by rays radiating from a single point; and the glass wall of the tube became overheated if a heavy current was used. The same objections do not hold as to a tube that is used for treatment if the tube can be applied directly or close to the tissues and if the current is a weak one. Tubes without an anticathode are usually made of lead glass except for a prolongation which is to be inserted into some cavity of the body, When in operation the main portion of such a tube (Fig. 485) lights up with a blue fluorescence and the prolongation shows the apple-green fluorescence characteristic of soda glass under the influence of the cathode ray. The cathode has the usual form of a concave aluminum mirror and directs the cathode rays into the prolongation, where by impact with the glass they give rise to x-rays which radiate from every part of the surface of the prolongation. The x-ray is distinctly perceptible if the fluoroscope is held close to the tube.

Fig. 486.—Unipolar x-ray tube.

Unipolar x-Ray Tubes.—Tesla, as long ago as 1896, devised an x-ray tube with only one electrode which was connected with one pole of a Tesla coil. The tube had a vacuum of one-millionth of an atmosphere and when applied to the surface of the body or to any other conductor acted in the same way as one of the modern ultraviolet vacuum electrodes. The back-and-forth surgings of the high-tension current caused cathode rays, when the current was in one direction, to impinge upon the glass and x-rays arose there. The unipolar x-ray tube devised by Stern of New York in 1905 (Fig. 486) has the additional feature of a concave aluminum mirror as the electrode, and during the periods when the current is in the right direction this is a cathode and focuses the cathode stream upon the anticathode which is near the part applied to the patient. There may also be a prolongation for x-ray treatment inside the nose or any other cavity.

The ordinary bipolar x-ray tube may act as a unipolar x-ray tube if the cathode alone is connected with the single terminal of a high-frequency apparatus capable of giving a 4-inch effluve. The tube is not to be in contact with the patient. Its radiance is sufficient for fluoroscopic work.

X-ray Tubes Without Any Internal Electrodes.—Pupin exhausted glass tubes to the x-ray degree of vacuum and connected the poles of the induction-coil to two pieces of tin-foil pasted on the outer surface of the bulb. A very good production of x-rays took place.

Guilloz's x-Ray Tubes (Fig. 487).—These tubes are large bianodic tubes which allow the use of very strong intensities and work satisfactorily on coils fed through a Wehnelt interrupter.

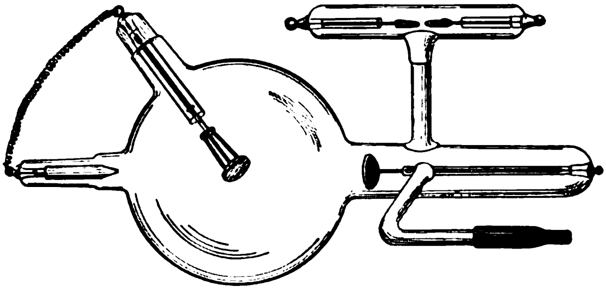

Fig. 487.—Tube of Professor Guilloz.

The anticathode is made of chromium, which is just as infusible as platinum and which is not volatile, so that it does not blacken the tubes even with the highest intensities. Chromium enables one to get the same quality of rays as platinum, but necessitates a more precise regulation of the equivalent resistance of the tube. In other words, the same variation in the equivalent resistance gives a greater variation in the hardness of the rays in the case of a chromium anticathode than in the case of a platinum one. Chromium may be platinized by electrolysis as well as iron, and thus are obtained voluminous anticathodes as lasting as platinum anticathodes of the same size, and having exactly the same properties for the emission of *x*-rays.

Chromium being hard and brittle and difficult to work, Dr. Guilloz has overcome the difficulty by pulverizing it and agglomerating the powder by strong hydraulic pressure. A small quantity of spongy platinum placed on the chromium before the application of the heavy pressure enables us to obtain tablets of platinized chromium which are hard and resistant enough to take the place of cast metal. The same method of agglutinization of metallic powders enables us to get anticathodic mirrors formed by conglomerates, the surface and the body of which are respectively constituted by substances we know to be desirable as anticathodic surfaces or as supports for anticathodic mirrors.

Guilloz has found that metallic hydrids, such as barium or calcium hydrid, have no appreciable tension of dissociation in the cathodic vacuum, and that an electric spark or effluve sent between two little electrodes made of these hydrids liberates hydrogen. These properties allow us to regenerate the gas necessary for the good working of a tube which has become too hard. To that effect, part of the current is diverted to two small accessory electrodes contained in the tube and carrying (either one or both) calcium hydrid on one of their extremities. These electrodes are prepared by keeping calcium hydrid cylinders in hydrogen gas at 650° C., but not long enough to have the metal attacked to the center; if the time of exposure were too long the electrode would be friable.

This regenerator is better than that formerly used by Guilloz, which was formed by thin sheets between which a spark was sent. The calcium hydrid electrodes have an unlimited regenerative power.

The tubes harden in the course of their natural use. They may become too soft if too strong a current has been used or too many sparks are sent into the regenerator. In the latter case a good vacuum may be restored by sending a weak current through the tube for a long time.

For a tooth picture or one of a hand any tube will be suitable which will give a good brilliant fluorescence in the fluoroscope and whose vacuum can be adjusted for the work in hand, but for the thicker portions of the body one of the heavy target tubes is always to be preferred, and for the most difficult work the operator, of course, will use the type of tube which he has found will stand a heavy current without marked change of vacuum.

The Coolidge *x*-Ray Tube.[1]—This is a tube in which there is practically a perfect vacuum. The cathode and anticathode are very close to each other, and the cathode, only ¼ inch in diameter, is formed of a flat spiral of tungsten wire, which, when heated by the current from a storage battery, liberates ions, and these carry the current across. The short space forms an absolute barrier to the passage of even the highest-tension current while the anticathode is cold, but when the ions are liberated by heating the cathode a potential of even 220 volts will send a current

[1] Wm. B. Coolidge, Physical Review, Dec., 1913.

through the tube, and, according to our accepted theory, should generate extremely soft *x*-rays. The hotter the cathode is made by adjusting the rheostat, so as to send more storage-battery current through it, the more ions are liberated and the more current is transmitted under the influence of a given potential. The quantity of *x*-rays produced increases in extent corresponding with the milliamperage, but the quality remains the same unless the voltage is changed. Instead of 220 volts electric-light current a high-tension current from one of the regular types of *x*-ray generators will commonly be employed and the *x*-rays are correspondingly harder. I purposely use the word soft and hard in this description. Soft rays are those of which a large percentage are absorbed by a thin layer of tissue, while only a small fraction of hard rays are absorbed by the same obstacle. The tube may be manufactured so as to have either a large or a small focus spot.

This tube represents a very important improvement in producing *x*-rays of approximately uniform quality, which can be regulated for various treatment and examination purposes, and of an intensity which may also be regulated within wide limits.

It presents some striking differences from previous *x*-ray tubes: The cathode is hot and luminous.

When actuated by a current of 25 ma. from an *x*-ray generator the anticathode soon acquires a cherry-red heat, with 50 ma. a white heat, and with 150 ma. it looks as if the anticathode might melt off and the tube be destroyed.

The tube does not exhibit the illuminated hemisphere characteristic of other *x*-ray tubes. This may indicate the absence of the secondary *x*-radiation from the glass wall of the tube, which I regard as the source of the secondary *x*-rays which have a blurring effect in radiography and ordinarily require the use of a diaphragm. This may prove of great advantage in not requiring a diaphragm.

A tube constructed on this principle is said to arrest inverse discharge and do away with the necessity for a ventril tube or a spark-gap.

The resistance of the tube is liable to drop suddenly under very heavy current, but will return to the normal as soon as the current is turned off.

Experiments by Cole[1] show that with a current of 30 ma. and a resistance equal to that of a parallel gap of 5 inches, an exposure of fifteen seconds is excellent for frontal sinus radiography; 5-inch parallel gap, 100 ma., and .06 second for a screen picture of the stomach; 1½ to 2 inch parallel gap, 25 ma., and two seconds for the hand.

An experiment by Cole shows that with a parallel gap, 7¾ inch, 10 to 8 ma., a total exposure of six minutes, with a screen of 3 mm. of aluminum, there was at 5½ inches from the anticathode a surface effect of 8 H., and at the further side of a piece of beefsteak, 2 inches thick, an effect of 4 H.

Inverse Discharge.—Some tubes will show the effect of the inverse discharge by lacking the sharp division into a light and a dark hemisphere and by an irregularity in the ray produced. This inverse discharge is a current produced in the secondary coil by the "make" in the primary current. Whenever a current begins to flow through the primary coil an induced current is generated in the secondary coil, and this is much weaker than the "break" current and in an opposite direction to it. This inverse discharge may not produce a noticeable

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[1] American Journal of Roentgenology, Jan., 1914, p. 125.

PLATE II

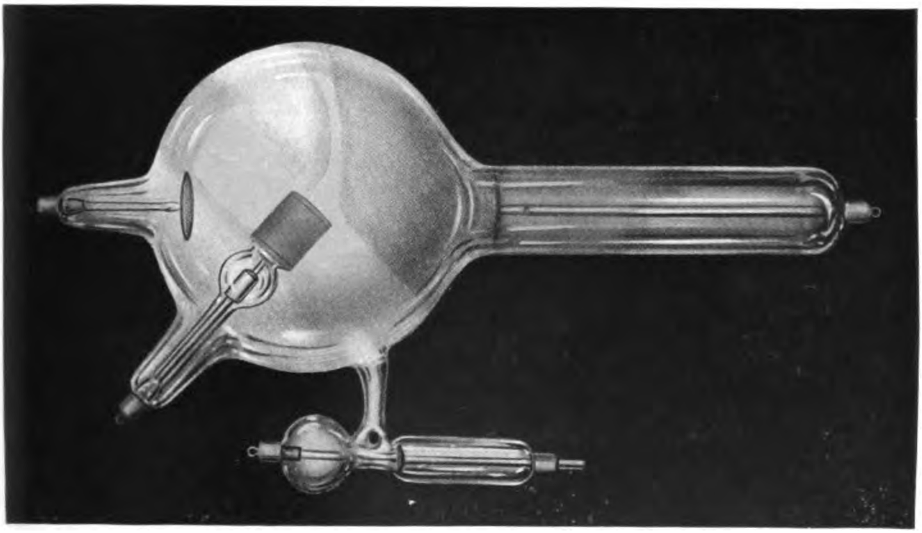


FIG. 1.—*X*-ray tube in operation. Exclusively inverse. Connected with the wrong poles of the *x*-ray coil.

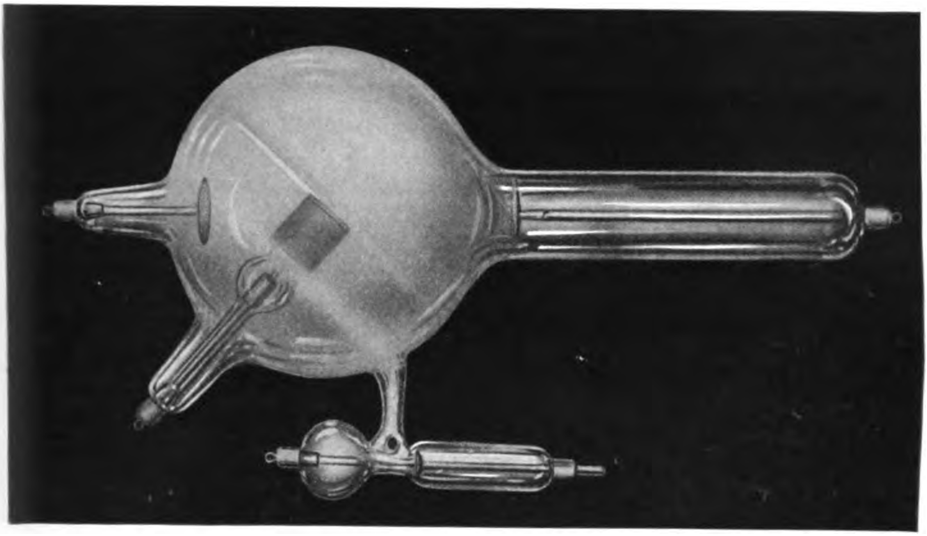
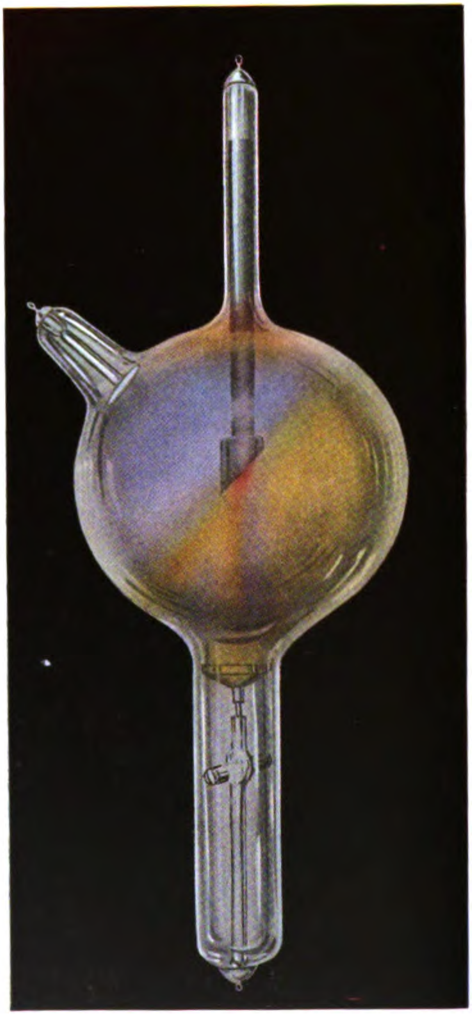


FIG. 2.—*X*-ray tube in operation. Considerable inverse discharge.

PLATE 12



X-ray tube in operation. Vacuum a little too low.

effect if the vacuum in the tube, the nature of the interruptions, the strength of the primary current and the self-inductance in the primary coil, and the adjustment of the condenser are all harmonious. When it does give trouble, it may be cut out by a spark-gap across which the secondary current has to leap in passing from each pole of the coil to the corresponding tip of the tube. These are properly called series spark-gaps as distinguished from the parallel spark-gap directly between the two poles of the coil by the length of which the resistance and hence the degree of vacuum in the tube is measured. The name multiple spark-gaps is applied to an arrangement by means of which the current may be made to leap across from one to six or eight short gaps on its way to the tube. It is doubtful whether this has any advantage over the simpler single gap of adjustable distance like the one devised by the author. Besides cutting out the inverse discharge which will seldom leap across a space of over an inch the spark-gap has a tendency to prevent overheating the tube and enables us to use a tube in which the vacuum is a little too low. It does not raise the vacuum, but produces a ray of a little more penetration corresponding to a higher vacuum.

The other special way of cutting out the inverse discharge is by the use of a ventril or valve tube. This is a vacuum tube of about the same size as an x-ray tube and has a regulator for maintaining the right degree of vacuum. Its positive and negative poles are differently shaped. One of the wires from the x-ray coil passes to one tip of the ventril tube; the current passes through the ventril tube and then through a wire passing from the other tip to the x-ray tube. This is quite a certain remedy for the inverse discharge, but is not an essential part of an x-ray equipment.

Ventril or Valve Tubes.—One pole of the Villard ventril tube is made of a spiral of aluminum presenting a very large surface for the origin of cathode rays. This pole acts readily as a cathode and the ventril tube permits the passage of currents flowing in such a direction that this pole is the negative one. The other pole is made of a small straight rod of metal almost completely ensheathed in glass and presenting a minimum surface for the origin of cathode rays. The tube will hardly transmit any currents which pass in such a direction that this becomes the negative pole of the tube.

If ventril tubes are used two of them should be provided and there are several different possible arrangements. One may be connected with either pole of the coil in such a way (Fig. 488 or Fig. 489) that the spiral of the ventril tube is connected either with the anode of the tube or with the negative pole of the x-ray coil. Or a ventril tube may be interposed between each pole of the x-ray coil and the appropriate pole of the x-ray tube, as in Fig. 490, taking care to have the correct poles of the two ventril tubes directed as specified above.

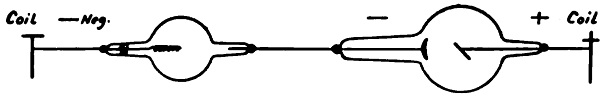


Fig. 488.—Single ventril tube connected in series with the cathode of the x-ray tube.

The third arrangement which should be provided for is to have one or two ventril tubes placed between the two poles of the x-ray coil, as in Fig. 491. During the normal discharge of the coil practically no current passes through the ventril tube, but during the inverse discharge. when the polarity of the induction-coil is the reverse of that shown in the diagram, practically all the current passes through the ventril tube. This occurs because the resistance of the ventril tube to the passage of a current in this direction is very much less than that of the x-ray tube.

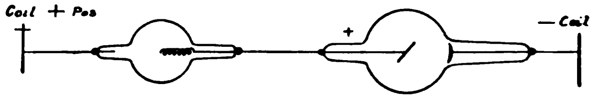


Fig. 489.—Single ventril tube connected in series with the anode of the x-ray tube.

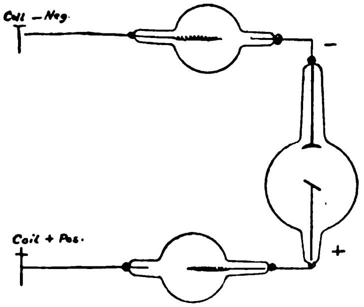


Fig. 490.—Ventril tubes between the poles of the coil and the terminals of the x-ray tube.

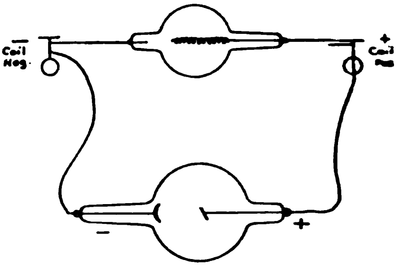


Fig. 491.—Ventril tube between the poles of the coil. Two may be used.

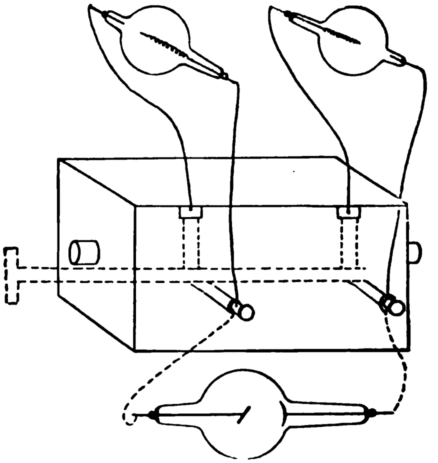


Fig. 492.—Author's arrangement of ventril tubes and spark-gaps.

This arrangement has been adopted by Gaiffe for his transformer, which is actuated by an alternating current without an interrupter. The discharge is alternating, the impulses in one direction pass through the ventril tube and those in the other and proper direction through the x-ray tube.

The Author's Arrangement of Spark-gaps and Ventril Tubes.—Each pole of the x-ray coil (Fig. 492) has a short metal base upon which is secured a glass rod about 4 inches long, and at the end of this rod is a metal attachment for the conducting cord leading to one pole of the x-ray tube. There is a movable metallic rod operated by an insulated handle which may be adjusted so as to make a direct connection between the corresponding pole of the coil and the cord leading to the *x*-ray tube by bridging across the insulated space represented by the glass rod. Or this metal rod may be turned back a little so that this space is not quite bridged over and the current has to leap across a spark-gap in passing from the coil to the tube. Or the metal rod may be turned back to the connection that leads to one of the ventril tubes. A ventril tube is held over each pole of the coil by a wooden bracket and its poles are permanently connected, one with the metallic attachment at the distal extremity of the glass rod and the other with an insulated attachment which can be reached by the metal rod when it is turned in that direction. The only way that the current can reach this pole of the *x*-ray tube when this connection is made is by passing through the ventril tube. The same arrangement is found at the other pole of the coil and each can be operated independently. The *x*-ray tube may be connected directly with each pole of the coil, or through a spark-gap at either or both poles, or through one or both ventril tubes. It is also only the work of a moment to connect one or both of the ventril tubes between the two poles of the *x*-ray coil.

Ventril tubes become overheated and break if the current is forced through them in the wrong direction. Even in the right direction they will not stand the heavy currents often used in radiography. The author finds them useful in radiotherapy arranged in series with the *x*-ray tube if the latter shows a tendency to inverse current, and arranged across between the poles of the *x*-ray coil in radiography, but ninety-nine times out of a hundred they are not required.

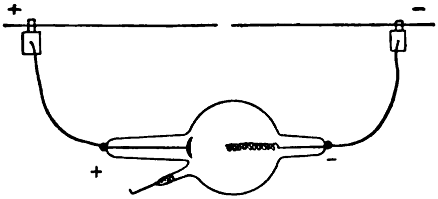


Fig. 493.—Current in proper direction through ventril tube.

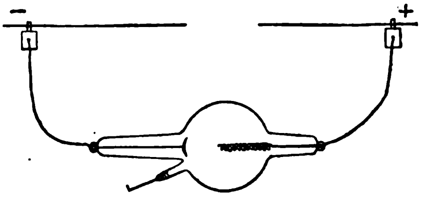


Fig. 494.—Current in the inverse direction through ventril tube produces an increased resistance and longer spark equivalent.

A ventril tube used in series with an *x*-ray tube producing rays No. 4 or 5 Benoist and consequently of proper condition for renal radiography should present a pale rose carmine color inside the aluminum spiral, the inside of the large part of the tube should present a rose-mauve color which becomes more pronounced toward the contracted part of the tube and changes to a clear rose color. At the anode there is a brilliant pink. In the prolongation into which the aluminum spiral extends there should be a faint red, not a green color, while the tube is in operation.

Regulation of a Ventril Tube.—For most purposes a ventril tube should have a resistance in the proper direction equal to a spark-gap of about 1 or 2 millimeters ($\frac{1}{25}$ to $\frac{1}{12}$ inch), while in the reverse direction its resistance should be from 4 to 7 centimeters ($1\frac{1}{2}$ to 2 or 3 inches). The degree of vacuum is regulated by means of a spark regulator, as in Fig. 493, or in other ventril tubes by heating the osmo-regulator.

The Wehnelt Valve or Ventril Tube.—This is a vacuum tube in which the cathode is composed of an infusible substance like carbon, platinum, or tantalum covered with a metallic oxid. When such a cathode is red hot a difference of potential of 18 or 20 volts will send a current through the tube in one direction, but it takes 300 volts to send a current through in the other direction.

It may be used to rectify an alternating current to be supplied to a Wehnelt interrupter and the primary of an induction-coil.

Such a valve tube may be used to rectify triphase currents. It requires three anodes connected with the three active wires and a single cathode connected with the neutral point. The current is then converted into a unidirectional pulsating one.

The Ondoscope or Oscilloscope (Fig. 495).—This is a glass tube about 12 inches long and about 1½ inches in diameter, closed at both ends, where electrodes are sealed in the glass and exhausted to the Geissler degree of vacuum. This is equal to 3 or 4 millimeters of mercury or a pressure of $\frac{2}{1000}$ or $\frac{3}{1000}$ of an atmosphere. The electrodes almost meet in the middle of the tube, coming to within $\frac{1}{25}$ inch of each other, where they may be separated by a vertical partition made of porcelain or mica, but in which there is a small central hole. The partition is not necessary. Any voltages above 300 cause the tube to light up around the end of one or both of the electrodes. The tube does not materially impede or affect the character of any of the high-tension currents which it is designed to study.

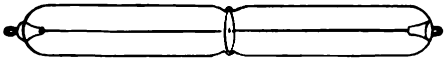


Fig. 495.—Rühmer's ondoscope.

It forms part of the circuit which is to be tested as to the magnitude and direction of high-tension currents. Placed in series with an x-ray tube a mass of violet light is seen to surround one electrode, while very little is around the other if there is little inverse discharge. Looking at the violet light in a rapidly revolving mirror it is seen to consist of separate flashes of light; larger ones in one direction, and alternate smaller ones in the other direction. A photograph made with the ondoscope (Fig. 496) furnishes a chart which shows the nature and direction of the discharges. Leduc and Morin[1] use the following method in making these photographs: A lens is placed near the ondoscope in a line with the opening in a diaphragm. The room is absolutely dark and a photographic plate is held at such a distance that the image is focused upon it. Moving the plate laterally secures a series of images of the successive flashes of light.

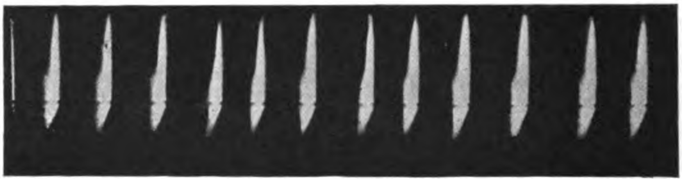


Fig. 496.—Discharge through x-ray tube and Caldwell-Simon interrupter, 3-cm. spark equivalent.

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[1] Arch. d'electricite med., Nov. 25, 1906.

The Caldwell-Simon interrupter gives better tracings (Fig. 496) than the Wehnelt and most others.

A very curious fact was brought out by varying the conditions in a mercury jet interrupter. The currents from the secondary coil become unidirectional when the duration of the period of closure is sufficiently small compared with the total time of a complete period.

This fact seems to the author to be suggestive of the practicability of so timing a mechanic interrupter as to secure unidirectional secondary discharges from an x-ray coil.

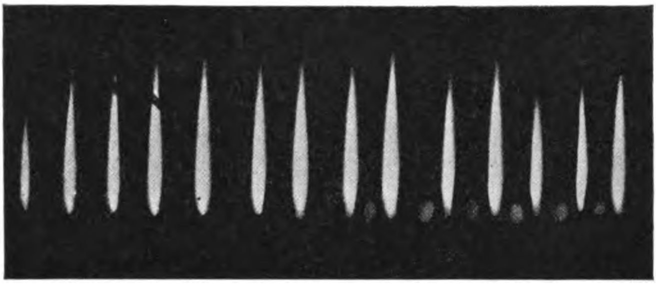

Fig. 497.—Same as Fig. 496. with 1-cm. spark equivalent.

The Author's Method of Ondoscopic Photography.—An ordinary camera is placed upon a stand upon which it may be turned from side to side. It is focused upon the ondoscope, placed in a vertical position, before the current is turned on. Then the room is darkened, the camera is turned to one side, and its diaphragm is opened. The current is now turned on and the camera turned quickly around. Its diaphragm is closed as soon as it has completely passed the ondoscope.

SECONDARY RAYS

These are x-rays, usually of moderate intensity, which arise from contact of the x-rays or the cathode rays with any solid or liquid substance. They radiate from all parts of the x-ray tube and from every portion of a solid or liquid substance traversed by the x-rays. Secondary rays from the x-ray tube may be called extra rays.

The intensity of the secondary rays from different substances has been found by J. J. Thomson[1] to be in proportion to their atomic weights, except in the case of nickel, which is the same as copper in this regard.

Secondary Rays from an Aluminum Screen for Soft Rays.—Secondary rays of slight penetration arise from an aluminum screen and are absorbed by the skin and have a tendency to create dermatitis. They may be arrested by covering the surface of the aluminum screen toward the patient with card-board or thick black paper.

Derma Rays.—This is the name sometimes applied to secondary rays of slight penetration arising from the impact of the cathode particles with the molecules of gas contained in an x-ray tube or with the glass walls of the tube. They are rays of slight penetration and are similar to the secondary rays which are generated in the skin from the impact of the x-rays. They expend all their energy upon the skin;

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[1] Proc. Comb. Phil. Soc., vol. xiv, 1907, p. 109.

hence the name derma. These are some of the rays which are arrested by protective filters for soft rays.

Experiments Upon Secondary Rays.—An experiment may be made in which the photographic plate in its light-proof envelopes is held with its uncoated surface toward the x-ray tube and with strips of platinum, lead, zinc, and aluminum held at the film side of the plate. The plate is much more darkened in front of the platinum, lead, or zinc strips than elsewhere. It seems like a reflection, but is probably due to the development of secondary rays from the metal surfaces. Aluminum gives rise to hardly any such effect, but a thin sheet of aluminum between the platinum and the photographic plate does not prevent the effect of the secondary rays which arise from the platinum.

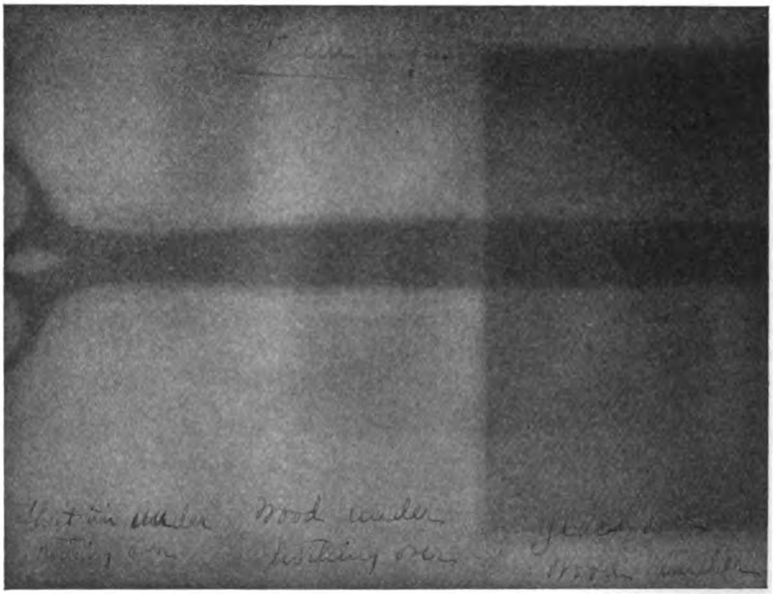

Fig. 498.—Experiment in halation. Film up. See text for different substances over and under the plate, outside of its light proof-envelopes.

Figs. 498 and 499, made by the author Dec., 1904, show the results. A pair of shears were laid upon a photographic plate enclosed in black and orange envelopes. In the first the film side of the plate was up and in the other it was down. In Fig. 498 a certain part of the plate had a sheet of glass over it and wood under it. This part of the plate was least acted upon by the x-rays. The other two portions of this plate were more acted upon. One had wood under and nothing but the paper envelopes over, and the third part had sheet tin under and nothing but paper envelopes over. The plate with the film side down (Fig. 499 showed the least effect from the x-rays at a portion with tin under and nothing over. The next to the least effect was where there was lead under and nothing over, and the greatest effect was where there was wood under and nothing over.

Courtade's experiments,[1].with tin, lead, copper, and aluminum placed

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[1] Bulletin offic. de la Societe française d'electrotherapie, Feb., 1906.

under a photographic plate exposed to the *x*-ray show that tin gives much more secondary rays than the others and aluminum gives practically none. Tin-foil may be spread over the sensitized surface which is turned away from the *x*-ray tube in order to secure the effect of an intensifying screen. This would succeed better with a celluloid film than with a glass plate, because with the latter the glass would intercept a certain part of the rays. Nothing is so good as a lead screen for the purpose of preventing secondary rays from reaching the plate from objects behind it.

Experiments by Kaye[1] indicate that screens of different metals are especially transparent to rays originating from an anticathode of the same metal or of a metal with a similar atomic weight. He also finds that with an aluminum screen and anticathodes of different metals the degree of opacity is almost directly proportional to the density of the different anticathodes. The theory is advanced that the *x*-rays arise partly in the deeper layers of the anticathode and undergo a certain filtration in emerging from it, so that the rays which radiate from it are largely those to which the particular metal is especially transparent.

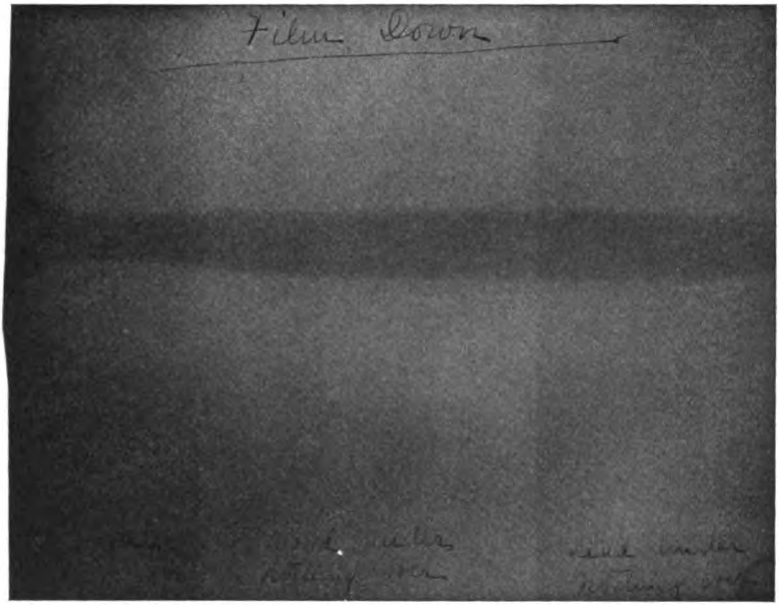

Fig. 499.—Experiment in halation. Film down. Different substances over and under the plate outside of its light-proof envelopes.

Lead transforms *x*-rays into more absorbable *x*-rays. Aluminum does not; hence a lead and an aluminum screen are more opaque than an aluminum and a lead one. Observations throw doubt upon this.

This is true of polonium rays, but hardly demonstrable with radium.

Diaphragms for the Suppression of Extra Rays.—Rays originate from almost every part of the tube, and cause the image to be slightly

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[1] Arch. Röntgen Ray, No. 93, April, 1908.

blurred as compared with an ideal condition limited entirely to the rays radiating from the focus-point on the anticathode. And it is possible by means of an ordinary diaphragm or series of diaphragms, or by means of Albers Schönberg's compression cylinder and diaphragm cylinder, or by means of the present author's cellular screen, to practically do away with the effect of these extra rays from the tube.

An ordinary diaphragm may be made of *x-ray metal* or of *lead* or *zinc* in any suitable support and with an opening which may be varied according to the necessities of the case. It may have the somewhat complicated arrangement called the iris diaphragm, by means of which the opening is varied from the largest to the smallest by the synchronous motion of a dozen different sections and the opening always remains circular.

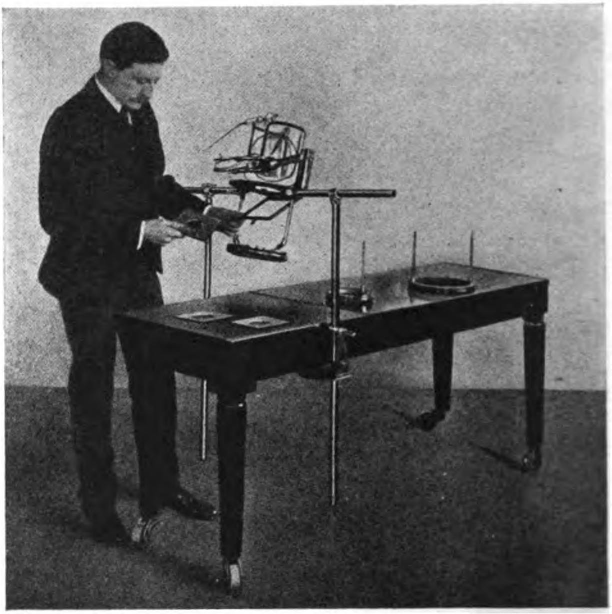

Fig. 500.—Röntgen radiographic table, lead-glass shield around *x*-ray tube (Röntgen Manufacturing Company).

An ordinary diaphragm which I find very satisfactory is that furnished by the *Friedlander shield.* This is a case which extends about two-thirds around the *x*-ray tube, and is made of felt lined with white lead, which is opaque to the *x*-rays. There is an opening opposite the anticathode to allow the exit of rays emerging at a right angle to the long axis of the tube. The opening is at a distance of 4½ inches from the anticathode and is 2½ inches in diameter. It may be reduced in size by the introduction of smaller diaphragms or of tubular prolongations which can be introduced into the mouth, rectum, or vagina, and, of course, are especially intended for treatment. The *x*-ray tube is securely fastened in the Friedlander shield and there is a stem to the shield by which it may be secured in any desired position by the *x*-ray stand.

The Friedlander shield affords all requisite protection for the patient, but does not shield the operator from the continued effect of the secondary rays arising from the uncovered part of the tube.

The *Ripperger shield* is an opaque box weighing 60 pounds and large enough to completely surround the x-ray tube, and affords entire protection except from rays emerging at an orifice which can be varied in size by the application of cylinders from 1 to 5 inches in diameter. It is suspended from a sort of gallows on wheels, so that it can be adjusted at any height above or below the patient and send the rays in any desired direction.

Similar shield boxes have been used by Albers Schönberg and others, but the mounting of this one renders it the most convenient of all.

Bergonié's[1] *method* of protecting the operator from the x-ray by having the tube close to the floor, so that the operator is above the plane of the anticathode, is insufficient. It is true that very few x-rays radiate from the back of the anticathode, and that for a single exposure a person is amply protected if he is behind the plane of the anticathode and consequently is not exposed to the direct rays. There are, however, extra rays arising from the illuminated surface of the tube and also from other parts of it and from every part of the room. Constantly repeated exposure to these indirect rays will surely injure the operator sooner or later.

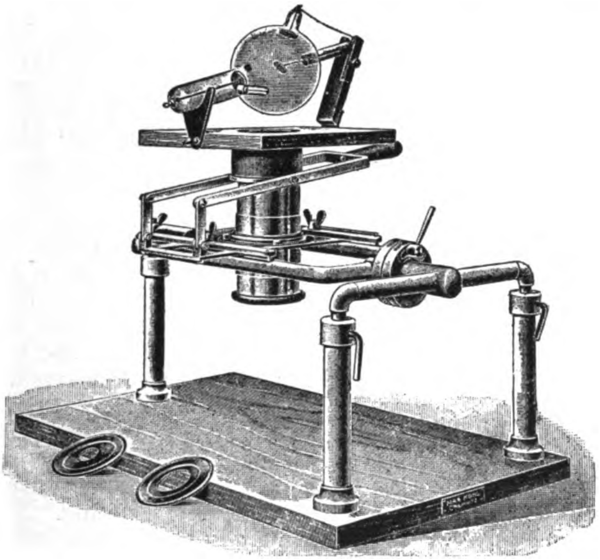

Fig. 501.—Compression cylinder and diaphragm.

Albers Schönberg's compression cylinder and diaphragm (Fig. 501) has a tube of brass lined with sheet lead either 4 or 5 inches in diameter and 4 inches long. The x-ray tube is held by clamps over a diaphragm of lead 1½ millimeters thick at the upper extremity of this tube and the lower end of the cylinder rests upon the surface of the body. There

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[1] C. R. de l'Acad. des Sciences, 140, 1566, June 5, 1905.

are supports by which the apparatus is fastened to the table on which the patient lies, and clamps and levers by means of which the lower end of the cylinder may be pressed firmly against the body and in exactly the best direction. It serves to keep the part motionless, as in the case of the elbow or ankle, and in addition to diminish the thickness of tissue in examination for renal calculi and other radiographs of the abdomen. The effect of the cylinder is to cut off the extra rays from a large part of the *x*-ray tube, depending, I think, chiefly upon the position of the diaphragm at the upper end of the cylinder. The only direct rays that can reach the plate are those embraced by two lines passing from the focus to the opposite sides of the cylinder, but these direct rays would require no diaphragm or cylinder at all. The object is to cut off the indirect rays, and as regards them the diagram of Albers Schönberg is too optimistic. My own diagrams show, I think, that secondary rays reach every part of the plate embraced by the widely radiating lines (Fig. 509, *b*), and that the image of a point *p* (Fig. 509, *c*) consists of the point produced by the direct ray obscured more or less by a penumbra from extra rays embraced between the two dotted lines. The amount of penumbra about each point of the image produced by the direct focus rays is the same, whether the diaphragm is supplemented by a cylinder or not, and is regulated by the size of the orifice in the diaphragm nearest the *x*-ray tube. The two sizes recommended by Albers Schönberg for use with the two different sized cylinders are 1 inch and 1½ inches in diameter. The diameter of the picture is 4 or 5 inches with the smaller diaphragm and 5 or 6 inches with the larger. All these facts are recognized by Albers Schönberg, showing the impossibility of obtaining theoretic perfection in the radiograph, but do not at all impair the value of the compression cylinder in cases where the lesion can be so definitely located that a picture 5 or 6 inches in diameter is large enough.

The Use of Loofah Sponge with a Compression Diaphragm.—This fibrous material can be made up into a hemisphere about 6 inches in diameter and should be covered with linen. Placed over the kidney region and pressed upon by the compression cylinder it displaces some folds of the intestine and empties others of their contents. The pressure also renders the tissues more or less anemic, and in this way aids in the production of a clear picture. This material is suggested by Strater.[1] It may also be used with the author's board compressor.

My own observations coincide with those of Albers Schönberg, that the diaphragm, with or without a cylinder, limits the focus rays strictly to those which are to form the 5- or 6-inch picture; and that in pictures through great thickness of tissue the secondary irradiation from the tissues is in this way very much less than if direct rays were shining through all the neighboring parts of the body. The secondary rays from the glass walls of the tube are probably all absorbed in passing through the tissues, so that his diagram may represent more nearly correctly than mine the condition which actually occurs in a picture through the body. My diagrams show what would be the result in taking a picture of objects at a distance from the plate but without much of a mass of tissue. The chest with the air-filled lungs would be such a case.

A small diaphragm, made of non-conducting material, so that it may

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[1] Zeitschrift, Feb., 1908.

be placed directly in contact with the glass wall of the *x*-ray tube and so give a conparatively wide angle of illumination, is indispensable.

The present author prefers his own board-compressor, with or without an air-filled rubber bag or a compression band (page 956), for reducing the thickness of tissue and for immobilization of the part. It enables a full-sized picture to be made, and will be described in greater detail in discussing the radiography of renal calculi.

Cole's observations[1] upon the secondary rays from an *x*-ray tube are important enough to be stated even if the present author does not entirely agree with them:

1. A new tube generally does not give good radiographs, no matter what type of apparatus is used to excite it.
2. This does not depend essentially on the degree of vacuum.
3. A well-made tube is easily brought to a stage where it will make a good picture if this seasoning is done gradually and carefully.
4. As it improves in radiographic quality its vacuum is better maintained.
5. After considerable service it is found difficult to lower the vacuum in the tube.
6. A stage is finally reached where one might suppose that the tube would soon be entirely unserviceable.
7. The tube is then in the best condition for radiography and will produce good pictures for a long time to come.
8. The dark color of the glass wall of the tube is, according to Cole, not due to a metallic deposit, but to a chemic change in the glass similar to that occurring in tubes containing radium.

Edema of the Tissues as a Cause of Lack of Definition in Radiography.—Radiographs of an injured elbow show the bones very much more clearly if they are taken before swelling sets in or after it has subsided. It would seem from the appearance of such a radiograph that the fluid must disperse the rays to a great extent, and not merely impede their progress along straight lines. Lichtenstein's experiment[2] in making a radiograph of an iron bar in a jar of water demonstrates this fact. The same author attributes the unsatisfactory results in radiography of the fetus in utero and in certain cases of calculi to the presence of the liquor amnii in the first case and of urine in the second.

The following experiment by the author shows that secondary rays arise from various parts of the *x*-ray tube besides the direct rays from the anticathode. This is in spite of the supposed unidirectional character of the discharges driven through the tube by the static machine:

A silver dollar was held up near to an *x*-ray tube actuated by a static machine, and looking through the fluoroscope a ten-cent piece, held in the shadow of the larger coin, could be seen perfectly well, unless it were held very close to the dollar. Enough *x*-rays passed around the edges of the silver dollar to illuminate the space, which would have been in absolute shadow if only the direct rays were present.

The same result is found with an induction-coil and either a Wehnelt, Caldwell, or mechanic interrupter. It is found whether ventril tubes are used or not, and arranging them in series at one or both poles of the *x*-ray tube or in shunt or parallel between the two poles does not prevent the same effect.

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[1] Arch. of the Röntgen Ray, No. 58.

[2] Münch Med. Woch., March 6, 1906, p. 4444.

The author's radiating diaphragm prevents this while still giving a large field for radiography.

An ordinary diaphragm or cylinder will prevent it if the opening is very small, but this gives a much smaller field for radiography.

That the effect is not due to rays passing through the silver dollar, and so making the penny visible, is shown by the fact that when a large sheet of the same metal is substituted for the silver dollar the penny ceases to be visible.

***X*-ray Filter or Screen for Soft Rays.**—The author attaches great importance to the screen for protecting the skin from the less penetrating rays. It may consist of a single thickness of tin-foil of which 100 square inches weigh an ounce. A sheet of sole-leather is still better, and the author employs it for every radiographic and most therapeutic exposures. Experiments show that its absorbent power is equal to that of about 1 inch of flesh, and with a very soft tube practically all the rays are arrested, as they are mostly rays of little penetration. With a tube of medium vacuum, the rays of little penetration are practically all arrested, while those rays which will penetrate several inches of flesh all pass through. This screen covers the orifice in a Friedlander or Ripperger shield and enables the tube to be brought much closer to the surface of the body than would be safe without it, and arrests most of the extra rays arising from the tube. It is a necessity for cases in which the object of interest is in a thick portion of the body or head, but is very close to the plate. Ordinarily the *x*-ray tube must be at such a distance from the plate that the image of the portion of the body nearest the tube is almost as dense as that of the object of interest, unless the latter is very close indeed to the plate. By means of this screen the anode is sometimes brought within 5 inches of the surface of the head or body, and the disproportion between the proximal and distal images becomes very great both in size and density. The case in which I find it most useful is in radiography of a fracture of the skull or in mastoid disease. In either case the image of the part of the head nearest the plate is clearer and the amount of exposure to the *x*-rays less than in the other way with the tube at a greater distance. Some other applications of this screen will be described in discussing the radiography of special regions.

The use of an aluminum screen for the purpose of protection from *x*-ray burn has not obtained very great favor, but probably the proper thickness to secure equal absorption would be efficacious in the author's screen for soft rays. A piece of ordinary thick sole-leather, as suggested by Pfahler, serves admirably.

There is a further reason for the use of the author's screen for soft rays in the fact that the various methods of radiometry do not enable us to determine the quantity of soft rays sent out by an *x*-ray tube, but practically only the amount of hard rays. This is the explanation of a hard tube occasionally producing a greater cutaneous reaction than would be expected even from a soft tube. Benoist's radiochromometer and the author's fluorometer show very plainly the amount of the penetrating rays, but with a certain amount of these rays the amount of the less penetrating rays will vary between very wide limits. This is notably true when a coil is used, owing to varying conditions in the interrupter, the tube, and elsewhere; it is not true to such an extent of the ray produced by a static machine. The screen for soft rays absorbs them, whether they are present in large or in small amounts, and acts as a shield against an undesirable effect upon the skin when it is desirable to bring the tube quite close to the surface, and the current must be a powerful one and the vacuum medium.

There is one danger in the use of the x-ray to which attention may be called at this place. It has been noted that with the tube at a very considerable distance from the surface of the body, the x-ray appears to act upon the deep tissues equally with the superficial tissues, and in treating a cancer of the breast a periostitis of the ribs has been excited; so that with the tube at too great a distance the less penetrating rays reach the body with greatly diminished power, aside from their natural divergence; while the more penetrating rays have suffered little loss of power from traversing the air; and any desired effect produced upon the superficial tissues under these conditions will be accompanied by an almost equal and, perhaps, undesirable effect on the deeper tissues. This observation is of especial importance in radiotherapy, but must be borne in mind whenever the human body is subjected to the action of the x-ray for either examination or treatment.

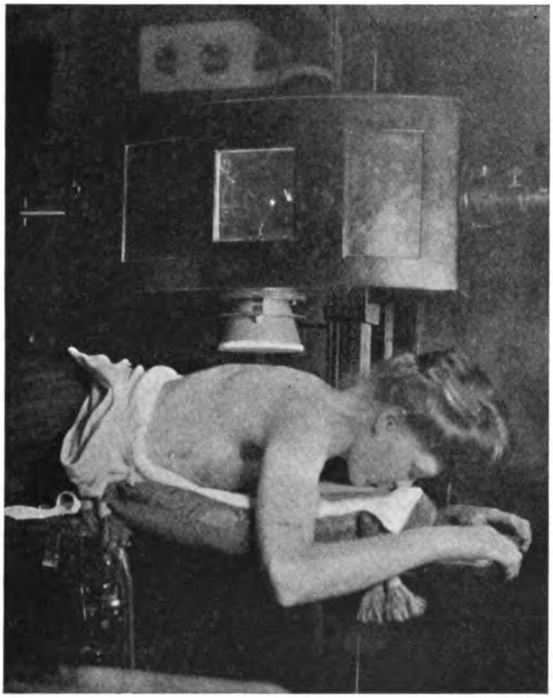

Fig. 502.—The author's radiating cellular diaphragm used with the Ripperger shield in radiography of the thorax.

As far as possible the important particulars of every radiograph in this book are given. Neither in these nor in any other ever taken by the author, or under his direction, has there ever been any burn or even a redness of the skin, and never any evidence of any other undesirable effect. Accidents of the kind do occur, however, and it seems to the author that the hundreds of hours which he and others have spent in experiments with radiographs of inanimate objects, and the study of apparatus and technic, will afford something of a guide to others.

The use of the author's screen for soft rays with a Friedlander or Ripperger shield enables one to take a picture safely, does away with extra rays from the tube, very much reduces the amount of secondary radiance originating in the tissues, and almost entirely prevents the access to the plate of secondary rays from the various parts of the room by suppressing the general diffusion from the *x*-ray tube. Pfahler's leather screen is usually employed.

X-ray Stand, Protective Shield, Diaphragm, and Cylinders Used by the Author.—This apparatus is made by Wappler, of New York, and the idea has been of gradual development. The tube is contained in a wooden box, coated on the inside with a sufficient number of layers of lead oxid to make it so opaque to the *x*-ray that no light can be seen in a fluoroscope held close to the box. Metal cylinders enter the box at the two ends and embrace the cathode and anode prolongations of the *x*-ray tube, and are adjustable so as to bring the focal point of the anticathode directly in the axis of the diaphragm. Electric connection is made by springs enclosed in these metal cylinders pressing gently against the terminals of the *x*-ray tube, while the conducting cords from the *x*-ray coil are attached to the outer ends of the metal cylinders. A number of lead-glass windows permit of observation of the tube while in operation. The box measures about 2 feet long, 1 foot high, and 11 inches wide; there is an opening 4 inches in diameter in the bottom of the box, and to this may be fastened a diaphragm with cross wires for preliminary use in placing the focus of the tube exactly in the axis of the diaphragm. After this adjustment the cross-wire diaphragm may be removed, and either the simple 4-inch diaphragm may be used or a cylinder may be attached. The different cylinders are 7 inches long and are 1, 2, 3, 4, and 5 inches in diameter, respectively. They are made of thick zinc, a metal almost as opaque to the *x*-ray as lead and more rigid than the latter.

The box as above described was suggested by Dr. Ripperger. It weighs 60 pounds and is held by a stand which permits the box to be turned in any direction, to be raised or lowered, and moved forward or backward. The tube stand is of the model suggested by Birckner. It is of wood and rests on a broad, flat tripod; a horizontal arm holds the box, and can be moved back and forth by turning the knob of a rack and pinion. This is useful in adjusting the tube for radiotherapy, and especially for stereoradiography. The weight of the box and horizontal arm is counterbalanced by a weight, like a window-sash weight, which slides up and down in one of the hollow wooden columns of the stand.

An improvement by the author allows of regulation of the degree of vacuum without opening the box. Two brass knobs, 6 inches apart on the outside of the box, are connected by springs, one with the cathode terminal and the other with the regulating device of the *x*-ray tube. A flexible wire is fastened to one knob, and may be bent so as to make a direct connection or a short or a long spark-gap between the regulating knobs. The entire apparatus weighs about 150 pounds, but it has rollers which enable one to push it over the floor. It costs about $100.

THE AUTHOR'S CONTACT DIAPHRAGM

This is made of a double thickness of the opaque fabric used in x-ray protective aprons. It sufficiently covers the anterior hemisphere of the x-ray tube, and has a circular opening 3 inches in diameter. The size of this opening may be temporarily reduced to 2½, 2, 1½, or 1 inch by an iris diaphragm, or by different sized rings of the same material. The opaque material employed is a non-conductor of electricity and does not interfere with the operation of the x-ray tube or cause it to be punctured.

The advantage to be derived is twofold: portability and increased area of illumination with equal definition.

The diaphragm adds so little to the weight that the tube can be held in an ordinary tube stand.

A diaphragm, *D–D*, of material which can be applied in contact with the wall of the x-ray tube will require a smaller opening for the same area of illumination upon the photographic plate than a diaphragm, *D′–D′*, which must be placed at a distance from the tube (Fig. 504). The same illustration shows the smaller area of the tube from which vagabond rays may pass through a point *X*. There is consequently very little blurring of the image as compared with that which would occur with a diaphragm placed at a distance from the wall of the tube (Fig. 505), where the opening in the diaphragm is large enough to give the same area of illumination. To secure equally good definition with a diaphragm at a distance, it would be necessary to reduce the size of its opening (Fig. 504) to that embraced at the level, *D′–D′*, between the dotted lines passing through *X*, and marking the limit of the opening in the contact diaphragm. The opening in the diaphragm, *D′–D′* (Figs. 504 and 505), may be the opening in a plane diaphragm or the proximal opening in a conic or in a cylindric one. The best effect with the

Fig. 503.—Flexible contact diaphragm, forming protective shield with openings of various sizes.

latter, of course, is obtained when the proximal opening is reduced by a plane diaphragm so as to really secure the benefit of a conic shape.

It seems from the foregoing that the diaphragm applied directly to the wall of the tube enables us to secure a wider field with equal definition. In actual practice a 3-inch diaphragm allows the radiograph to cover the whole of a 14×17-inch photographic plate, 22 inches from the anticathode, and shows both kidneys, ureters, the bladder, and prostate; and a 1-inch diaphragm embraces the entire pneumatic sinus area of the face. The latter may be excellently observed in the fluoroscope, if the operator cares to run the risk of injury, and a radiograph is easily made after centering the rays under actual observation. A 1½-inch diaphragm gives sufficiently good definition, and as it takes in the entire face the fluoroscope need not be used in centering the rays.

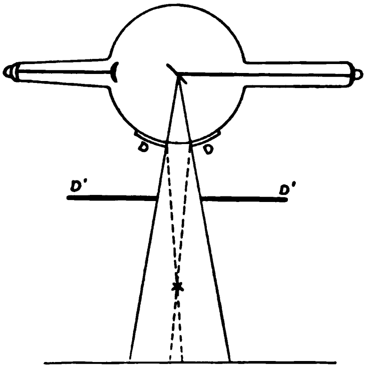

Fig. 504.—*D–D*, Tousey's contact diaphragm; smaller opening and much less blurring than with ordinary diaphragm *D'–D'*.

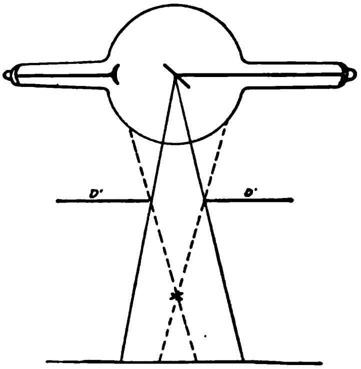

Fig. 505.—Large opening and greater amount of blurring with ordinary diaphragm giving same area of illumination as with Tousey's contact diaphragm (compare Fig. 504).

X-ray-proof Aprons, Gloves, and Spectacles.—Sheet rubber containing baryta or lead oxid may be made as opaque as desired to the x-ray. It may be cut into aprons or gloves to protect the operator, or into appropriate sizes and shapes to limit the field of exposure in radiotherapy.

Spectacles of flint glass containing a large percentage of lead are a valuable protection for the operator's eyes in fluoroscopic work. It must be remembered, also, that even the reduced fraction of the radiation which will pass through the entire thickness of the patient's body is injurious to the operator, who is often exposed to it.

A sheet of lead glass covering the barium-platinocyanid surface of a fluoroscent screen enables one to see the image perfectly well while it protects the operator's face from the rays.

X-ray-proof Gloves.[1]—Soak thick leather gloves in a saturated solution of bismuth chlorid, then immerse them in cold running water for an hour, dry them thoroughly, and repeat the process two or three times. An interstitial deposit of oxychlorid of bismuth is formed.

Material for x-Ray-proof Garments.—An improved material has just been imported into this country. It consists of two sheets of strong cotton cloth between which is a thick layer of rubber containing

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[1] Dr. Wm. Mitchell, Arch. of Röntgen Ray, April, 1908.

a certain percentage of lead. It is much more durable than the materials previously in use. The outer surfaces are sufficiently coated with the same rubber composition to be water-proof.

The Fluoroscope.—A fluoroscopic screen is usually a sheet of card-board coated on one side with barium-platinocyanid, a chemical which becomes brightly fluorescent when exposed to the *x*-ray. Tungstate of calcium can be used in the same way. The latter gives a white and the former a greenish light. In a dark room the patient stands between the observer and the *x*-ray tube, and the screen is held close to the patient with its chemically coated surface toward the observer. With the proper amount of radiance a picture is seen upon the fluorescent surface of the screen, which is really a shadow-picture, representing the different densities of the parts under observation. For most purposes it is more convenient to have the screen form the end of a dark box, which enables us to use the screen without darkening the room.

The accessory apparatus and the details of technic are considered in the chapters on Radiography, Fluoroscopy, and Radiotherapy.

A Home-made Calcium-tungstate Screen.—The materials required are 1 oz. sodium chlorid, 1 oz. sodium tungstate, and 1 oz. calcium chlorid. Powder these together and put them in a crucible with a tin cover and set right in a fire with glowing coals heaped around it for two or three hours. The compound is converted into a clear liquid which crystallizes into a glass-like mass on cooling. Break this up into a coarse powder, put it in water, which will dissolve out the sodium chlorid, and fine crystals of calcium tungstate will settle to the bottom. Pour off the water, add more water, and decant. Do this several times until all taste of salt disappears. This part of the process takes twenty-four hours. Pour the sediment on a sheet of blotting-paper and dry in the sunlight. Coat a piece of tracing paper or linen cloth with flexible collodion or glue and sprinkle the fine, dry crystalline powder over it. Repeat the coating with collodion or glue and the sprinkling with calcium-tungstate crystals two or three times. (The total cost of the materials including the crucible is only about 20 cents.) (Kolle, "*X*-rays.")

Intensifying Screens.—If a photographic plate is enclosed in the same cassette, or entirely enclosed plate-holder, with a means of pressing the two chemic surfaces close together, exposure to the *x*-ray will produce a double effect. First, there will be the image produced upon the photographic plate by the *x*-ray and, second, the image produced upon the plate by the bright fluorescent light which occurs on the screen. With the modern intensifying screen, the latter effect is ten times as great and completely overshadows the direct *x*-ray effect. There are some advantages connected with the tungstate of calcium screen for intensifying, because it gives a whiter light than the barium platinocyanid screen, which is more generally used for fluoroscopic examinations.

Intensifying screens greatly shorten the time of exposure. The best ones, like those made by Dr. Threlkeld-Edwards, of South Bethlehem, Penna., U. S., reduce the time to one-tenth of the ordinary exposure. The poorest ones reduce the time only one-half, and so are practically worthless. With the increase in speed there is some loss of detail, as, for instance, in the structure of the bones. As a consequence, it would not be desirable to use an intensifying screen for making a radiograph of the hand. Even with a weak, portable *x*-ray outfit, it is practicable to obtain a direct radiograph of the hand without an excessive exposure. It is a different matter, however, when the thigh or body of a large person must be radiographed with a portable outfit, and also when a number of radiographs must be made through the body, as for an examination of the shape and position of the stomach and intestines, after a bismuth meal or enema, even with the most powerful apparatus. In these cases safety to the patient and convenience and economy of wear and tear upon apparatus, and the desirability of snapshots of moving parts, call for the employment of an intensifying screen. A good intensifying screen has become an essential part of the equipment of a Röntgen-ray laboratory.

The best screens are exceedingly fine grained, and show very little of the structure of the screen upon the photographic plate if the exposure and development have been right.

The choice of the plate for screen work is important. One like the Imperial *x*-ray plate, with a thin sensitized coating, gives better results for this purpose than the thicker coated Ilford *x*-ray plates, which are so much better for direct radiography.

In making the exposure the glass side of the plate should be toward the *x*-ray tube and the sensitized surface toward the intensifying screen.

For the best detail the exposure should be such that the plate will show the proper density after fifteen to thirty minutes' development with the Threlkeld-Edwards developer. More commonly a stronger exposure is given which requires only three or four minutes' development.

An over-exposure causes the image to flash up so quickly that the plate is fully developed in about two minutes, and shows every grain of the intensifying screen. It is evidenced at once by the appearance of the intensifying screen when the plate is removed in the dark room. The portion of the screen covered by the thicker parts of the patient should not show a bright persistent fluorescence.

Threlkeld-Edwards Developer for Screen Plates.

Water (distilled)	48 ounces.
Sodium sulphite (dry)	2 ounces.
Hydroquinone	5 drams.
Eikonogen	½ dram.
Potassium carbonate (dry)	4½ ounces.
Potassium bromid (25 per cent. solution)	5 drams.

(One dram equals 4.0 grammes, and 1 ounce equals 32 grammes.)

The loss of definition in consequence of the granular character of the fluorescent surface is not deceptive in any way, and a reduced copy of a picture made in this way does not show the granular appearance. Radiography of the chest is a case in which very short exposures are likely to be more useful than those of medium duration. Even here the discovery of commencing consolidation is better made without an intensifying screen, seeking the element of speed in a brilliant radiance and a sensitive plate, and having the patient hold his breath during the exposure. This, however, is also one of the cases in which a fluoroscopic examination would have advantages over the radiograph except for its danger.

The different factors have been considered at length because of the assistance this may afford to others. To learn the successful and safe use of the x-ray one must try to profit by the hundreds of hours spent by others in study and experiment, and must also expend a similar amount of time, money, and labor in practical work with the apparatus.

THE SENSITIVENESS OF THE FILM, PLATE, OR PAPER

The dry plates sold by the various manufacturers of photographic supplies under the name of x-ray plates have about the best degree of sensitiveness and are often made with a double or triple coating. The latter gives density to the picture, adds slightly to the speed of the plate, but adds very greatly to the time and care required for development. For some reasons it seems best, under certain conditions, to use the most rapid regular daylight plates, of which the Cramer Crown plate may be mentioned as an example. The daylight plates are in use in large numbers everywhere and hence may be more easily secured in a fresh condition than the special x-ray plates. The kodak film produces an excellent x-ray picture, but according to my own observations is about one-third as rapid as the Cramer Crown plates. The special triple-coated x-ray films, prepared by the Seed Dry Plate Company for use in radiography of the teeth, are of about the same speed as the Cramer Crown Plates. A series of experiments have been made by the author to determine the relative speed of the x-ray and gaslight. It was found that gaslight was many times more rapid than the x-ray. The comparison was made between a 3-foot gas-burner at a distance of 5 feet and a heavy target Müller tube with a resistance of 2½ inches, 12-inch coil with large self-inductance; Caldwell interrupter, 9 amperes, no rheostat resistance; and Cramer x-ray plate in black and orange envelopes, 11 inches from anticathode, different parts exposed fifteen, thirty, sixty, and one hundred and twenty seconds. The portion of a similar plate which was exposed to gaslight for forty seconds was as dense as that exposed to the x-ray for three times as long. Both plates were developed in exactly the same way and for the same length of time. It will be seen that the photochemic effect of the x-ray from a tube giving a brilliant radiance is only one-third as great as that of a small gas-jet at five times the distance. Taking the relative distances into account, the difference in power is about *75 to 1 in favor of the gaslight.* Sunlight, of course, is incomparably more effective than the x-ray, photographically. The wonderful thing about the x-ray is not the amount of effect it has on a photographic plate, but that its effect is produced even after passage through great thicknesses of animal tissues and other opaque substances.

The Lumiere Sigma plates and films are four times as rapid as the fastest made in America and are excellent for x-ray work. Schleussner's x-ray plates are also good, but not as fast.

The sensitiveness of regular bromid paper is about one-fifth that of a regular plate. This makes it suitable only for the extremities and the teeth. To make a good picture of any portion of the trunk upon this paper would require a dangerously long exposure. We sometimes use one or more pieces of bromid paper exposed at the same time as the film or plate for pictures of the teeth, hands, or feet. It enables us to get an immediate picture, not so good as it would be if we were to give it the longer exposure which the paper really requires, but which is useful as a proof. It shows whether the position has been a successful one or not. The bromid paper alone is splendid for cases in which an *x*-ray diagnosis is required immediately, as for the removal of a foreign body or the treatment of an obscure injury. The picture may be developed at once without a dark-room, but in a faint light, and is made upon the same identical piece of paper which is exposed to the *x*-ray. This exposure is a very great deal shorter than is required for a fluoroscopic examination in a case of any difficulty and prevents the possibility of a burn, either of the patient or the physician, and it will frequently show a needle or splinter which cannot be detected by the fluoroscope. In consequence, perhaps, of an article of mine upon this method[1] its use has become generally known, and in several instances physicians have written me of its successful application in cases where the fluoroscope had failed and where the necessary apparatus and technic for developing a plate were wanting.

Röntgen paper is now made as sensitive as the usual *x*-ray plate and suitable for all kinds of radiography. It is a bromid paper, but requires to be developed by ruby light.

The less sensitive photographic plates are entirely unsuited to general radiography. An exposure which will produce a good picture on the right kind of plate will often not show a trace of structure upon one of the less sensitive plates. There are many different degrees of sensitiveness in the plates made by the same manufacturer. Some are intended for one purpose and some for another, but when it is considered that the *x*-ray is only about one-seventy-fifth as rapid as a moderate gaslight, it will readily be seen that only plates of the highest sensitiveness are suitable. To produce a good picture through any thick portion of the body upon one of the less sensitive plates would require a dangerous exposure to the *x*-ray.

Halation in photography is supposed to be the result of a reflection of light back from the further surface of the plate. Its effect becomes apparent when a photograph is taken of a very brightly illuminated object with sharp outlines. Such a picture might be taken with the camera pointed toward a window with small panes and with bright daylight outside. Instead of what we are accustomed to speak of as photographic sharpness, we would obtain a picture showing blurred outlines of the cross-bars separating the panes, as if the effect of the brilliant light of the panes had extended partly to the dark portion of the plate upon which the image of the cross-bars is impressed. Various remedies have been tried to prevent this reflection, and what are known as non-halation plates are considered the best. In effect these are plates with a double thickness of film, so that almost all the light is arrested, and the resulting image is so dense that the slight reflection which may still be present does not show upon the picture. All the celluloid films are almost free from halation. Experimenting as to halation the author has made radiographs of sharply defined metallic objects, such as coins and needles, placed practically in contact with the plate and with the *x*-ray falling in some cases vertically, and in others at various angles, up to the greatest angle ever required in practice. In the entire series of experiments there was no effect of the nature of halation produced. One clinical radiograph did show a blurred image of the leaden figures used to mark the number of the picture, but dupli-

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[1] Tousey, An Improvement in Radiography, N. Y. Medical Journal, August 29, 1903.

cating all the conditions a perfectly clear image resulted, and it seems certain that the figures must have been accidentally moved during the interval between the first and second parts of the exposure. The purpose of having the objects as near as possible to the plate is to eliminate the aberration which inevitably occurs in the image of an object at any distance from the plate and which has no relation at all to the special condition produced by a diffuse reflection from the back of the plate. My experiments have led to the conclusion that halation is not a disturbing factor in radiography, and that celluloid films or double- or triple-coated plates, are not required on this particular account. Celluloid films, coated on both sides with an especially sensitive emulsion, are made by some of the manufacturers, especially in Europe, for instantaneous radiography of the chest, and are intended to be used between two intensifying screens.

The Duration of the Exposure.—The length of time required to produce a radiograph is influenced by the different factors already discussed. The absolute safety of the patient should be the first consideration, the next consideration should be a perfect picture, and finally the time of exposure should be as short as is consistent with the first two elements and with economy of wear and tear upon the apparatus. Other conditions being the same, the time of exposure is very greatly shortened by increasing the strength of the primary current. In some experiments of my own the result has been that doubling the amperage of the primary current has reduced the time required for a radiograph tenfold. In the early days of the use of the *x*-ray some operators adopted the plan of not commencing to count the time until the anticathode had become red hot "and the tube had reached its maximum efficiency." Practically every one of the pictures in this book were completed before the anticathode became red hot, and so, according to this reckoning, were taken in less than no time. In the case of the heart, and possibly the lungs, it is sometimes preferable to take a picture in a very short time while the patient holds his breath. By using an especially sensitive double-coated celluloid film between two intensifying screens and a primary current of from 20 to 30 amperes, such a picture can be taken in about a second. On an ordinary *x*-ray-plate and with a current of 20 amperes the time for a good picture would be about twenty seconds, and with the same conditions a picture of the pelvis would be made in forty seconds and of the hand in one or two seconds. Varying the conditions as to vacuum a little from my standard as to what produces the best picture and increasing the strength of the current, the time for a pelvic picture may easily be reduced to fifteen seconds. The very heavy currents required for short exposures are a strain upon the secondary coil, upon the interrupter, and upon the tube. This is in addition to the less serious, but none the less annoying, burning out of fuses. Assuming that one's apparatus is capable of producing practically the greatest possible *x*-radiance with a given strength of current, and that one knows how to get the best results from it, the following would be a desirable schedule:

With an induction-coil:

Hand or teeth	5 to 30 seconds.
Elbow or foot	10 to 50 "
Shoulder, chest, or knee	15 to 120 "
Pelvis, head, vertebræ, renal calculi	40 to 200 "

The longer time mentioned under each heading will suffice to make a good radiograph with a good coil and technic, but with a moderate strength of current. The shorter time given requires a great deal more study of the subject and an apparatus which will stand heavy currents. Still shorter exposures may be obtained, either by the sacrifice of quality in the radiograph or increasing the size of the coil and the strength of the primary current, about 40 amperes being the limit of the latter. This presents still greater technical difficulties and increases the danger of injury to the tube or coil. In considering radiography of the individual parts of the body examples are given which show fairly the time required under different conditions. **Transformers have reduced the exposures.**

With a transformer:

Hand or teeth	½ to 2 seconds.
Elbow or foot	1 to 5 "
Shoulder, chest, or elbow	1½ to 7½ "
Pelvis, head, vertebræ, renal calculi	4 to 20 "

An *intensifying screen* reduces the above exposures to one-tenth or less.

The rays which produce an effect on a photographic plate are the ones whose influence upon living tissues must be taken into account. With too low a vacuum one might fail to get a radiograph through the lumbar region, even though the *x*-ray were turned on long and strong enough to produce a severe burn, and the same may be true of *x*-radiance of the right quality but from too weak an apparatus. In either case the little photochemic energy which does reach the plate would act so slowly that before the exposure was complete a dangerous effect would have been produced upon the tissues of the patient. A famous medicolegal case was that of a patient of Prof. Hoffa, of Berlin, in which case an exposure of forty-five minutes was required for a radiograph of the hip-joint, and a burn resulted. The patient had previously been exposed to the *x*-ray by some other physician. The case was dismissed because the exposure was in conformity with the best technic available at that time. Improvements in every part of the *x*-ray equipment have so much reduced the time of exposure as to make it possible to take a good picture of any part of the body with practically no risk of any sort to the patient. This means that the patient is only exposed to an entirely safe amount of *x*-radiance for even the most difficult picture, and if the conditions are observed upon which my table is based it is quite safe to take two different pictures of the same part at the same session. This is true of the body, and for the teeth and hands several exposures may be made. The element of time alone will not secure a good picture. I have known a man with a good 8-inch coil to give an exposure of six minutes for a kidney-stone and obtain no picture, and an exposure at another session for sixteen minutes and find nothing on the plate. This resulted in a severe burn of the abdomen. A sufficient time of exposure is absolutely necessary, but it must be combined with correct details throughout. Overexposure is undesirable, but may be corrected to some extent during development, and besides, the finished plate may if necessary be examined by a strong transmitted light, so that a plate which would be practically useless from the standpoint of the daylight photographer may still prove very good for the diagnosis and record of the case. The safe amount of time during which a patient may be exposed to the *x*-ray is dependent upon the intensity of the *x*-radiance and slightly upon idiosyncrasy. At a distance of 9 inches from the anticathode to the surface of the body, and with a tube of medium vacuum and an intensity which permits the bones of the hand to be seen faintly, nine minutes would be the maximum safe exposure without any previous experience with the individual patient. Such an exposure might produce a good picture of an extremity or possibly of the chest, but absolutely nothing of the pelvis, and with such radiance an exposure even twice as long as would be safe would not result in a picture of the lumbar region. The other extreme would be an *x*-radiance so powerful that a pelvic picture may be made in fifteen seconds or less. There is, theoretically, no danger to the patient, but practically it is only in the most expert hands that success is certain at the first attempt. The employment of any such powerful current is dangerous if the exposure is prolonged, or if the exposure has to be made repeatedly, and this, of course, would be the case in inexperienced hands. It is very much better to learn to take perfect pictures with a moderate length of exposure, and to consider 15 amperes with a 110-volt primary current as the very outside limit, until one may fairly claim to know the *x*-ray thoroughly from personal experience. The principal injury which may occur to the tube from too strong a current in the effort to shorten the time of exposure is either a puncture of the glass wall of the tube or fusing the platinum coating on the anticathode. A secondary coil which burns out in consequence of too heavy a current is a total wreck and may do considerable damage to its surroundings. The thousands of feet of fine wire are insulated in a mass of wax, and when the wire fuses from an overcharge the wax melts and fairly explodes. Of course, every coil is made to stand a current of a certain strength and for a certain length of time and this limit should not be exceeded. An exposure of one hundred seconds with a primary current of 12 to 15 amperes may often be advantageously divided into three of about thirty seconds. Several exposures of fifteen seconds separated by intervals to allow the tube to cool often give the best results. Very few tubes indeed will maintain the same degree of vacuum during one hundred seconds with a charge produced by a current of 12 to 15 amperes, and, of course, after a marked change has taken place the balance of the exposure is worse than wasted. During this time the patient must repeatedly be cautioned to stay still and, of course, it is going to be best to have the plate flat upon a table with the part to be radiographed resting upon it.

Radiographs of the head or abdomen with a single uninterrupted exposure without injury to the tube may be made with a heavy anticathode tube, such as the high-frequency tube described on p. 739, a 12-inch induction-coil, a primary current of 18 amperes, and an exposure of thirty seconds. This is the time required for a photographic plate, but it may be reduced to three or four seconds if a celluloid film between two intensifying screens is used.

Rapid radiography is obtained with alternating or direct current transformers. Pelvic pictures in one or two seconds, thorax in one-quarter second (see p. 722).

The Nature of the Materials in Contact With the Plate.—The usual practice is to place an *x*-ray plate in a black envelope and outside of this an orange envelope. This must be done in absolute darkness or else in a photographer's dark-room illuminated only faintly by a ruby lamp. The film-surface of the plate may be recognized by its dull reflection of the ruby light and if necessary by the fact that a moistened finger-tip will stick lightly to it. In placing it in the envelopes care should be taken not to scratch the film-surface or to touch it with the fingers. Either of these will produce a mark upon the plate and mar the picture. The plates should not be placed in these envelopes by the dealer, for the film becomes damaged and fogged by long contact with the paper, and I have rather frequently seen a line produced on a plate by the paste used in making the envelope. This line passes down the center of the plate and produces an effect similar to that from a streak of daylight falling upon the plate. This effect is not so ruinous upon a plate used for taking a picture of the hand, where the contrast may be made so brilliant that the slight fogging is not noticeable. The background on such a plate may be made a dense black, and even if the high lights are not quite so transparent as they might be, the picture may still prove very satisfactory. When such a plate is used for a radiograph through the body, however, the slight contrast produced by the x-ray, and the prolonged development required, may result in a plate which shows principally the grain of the black envelope and the streak of paste down its center. These black and orange envelopes should not be regarded as sufficient protection against ordinary light except just during the manipulations of taking the picture, and they are no protection at all against the x-ray. The plates are best kept in the original boxes until shortly before use; and before and after use should be wrapped in opaque material outside of the black and orange envelopes. One curious plate of mine shows all the printing on the x-ray envelope, and this was probably the effect of exposure to ordinary light. Needless to say the plate was so fogged that it was barely possible to make out that it was a picture of an ankle. Fig. 506 is an example of a plate ruined in this way. The ordinary plate-holders used by photographers are excellent and produce no deleterious effect upon the plates, which can be kept in them as long as desired. They afford no protection against the x-ray, however, and, therefore, there is no advantage in their holding more than one plate unless it is desired to take two pictures at the same time. A simple and effective *plate-holder* has been suggested by Gagnere.[1] It consists of a box such as a dozen or half a dozen plates are sold in, partially

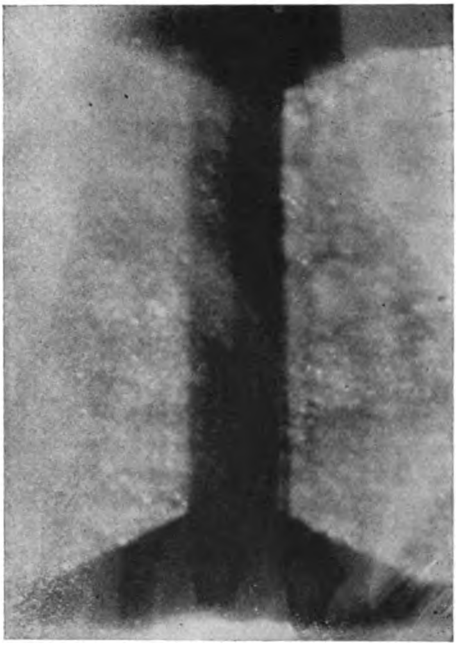

Fig. 506.—Plate fogged by contact with envelopes and by sunlight penetrating them.

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[1] Archives d'Electricite Medicale, Bordeaux, Dec. 10, 1904.

filled by a board of the same length and breadth as the plate. The film side of the plate is protected from contact with the cover of the box by small pieces of card-board pasted on the corners of the same. The plate is placed in such a box without any wrapping and will undergo no change from a chemic effect due to the container or from exposure to ordinary light. The presence of the board backing inside of the box is an element of safety from the very disagreeable accident of having the plate break. To prevent the plate from breaking when using the ordinary black and orange envelopes, the whole may be placed in a plate-holder made of wood with a shallow depression and a thin wooden cover.

Two plates face to face in light-proof envelopes remain in good condition for a long time.

Stereoscopic Radiography.—The same sort of plate-holder is useful for stereoscopic radiography, in which case it is necessary to take successive pictures on two different plates which are placed in exactly the same position and without any movement on the part of the patient. The *x*-ray tube is shifted a few inches after the first exposure and the distance that it is moved corresponds with the thickness of the part and the distance of the tube from the plate. The result is two different pictures which may be optically fused into one picture by examining both original plates in Weigel's modification of the Wheatstone stereoscope, or by examining reduced copies of both plates in the ordinary hand stereoscope with its prismatic lenses. Ordinarily in looking at any object or group of objects, of course, each eye sees quite a different picture, but the brain combines the two impressions into one picture, which has the property of perspective. This enables us to recognize at a glance whether one part of the object is projecting toward or away from us, and this without any regard to the relative size of its image. Of course, skilful drawing will sometimes cause an image on a flat surface to appear to stand right out. Theoretically, the two pictures in stereoscopic photography or stereoscopic radiography should be taken from points of view just as far apart as the pupils of the two eyes, but practically it has been found desirable, both with the camera and with the *x*-ray, to vary this distance in accordance with the subject of the picture. In other words, it is often necessary to exaggerate or diminish the stereoscopic effect in order to produce the best perspective. The following table, worked out by Marie and Ribaut,[1] is a useful guide, but as long as the distance that the tube is shifted is recorded, the exact distance given in the table need not be followed:

MARIE AND RIBAUT'S TABLE

Thickness of the part radiographed.	Distance from the anticathode to the surface of the body.				
	20	30	40	50	Centimeters.
2 cm.	4.4 cm.	9.6 cm.	16.2 cm.	....	Distance to which the tube must be displaced.
4 “	2.4 “	5.4 “	8.8 “	13.5 cm.	
6 “	1.7 “	3.6 “	6.1 “	9.3 “	
8 “	1.4 “	2.8 “	4.1 “	7.3 “	
10 “	1.2 “	2.4 “	4.0 “	6.0 “	
15 “	....	1.8 “	2.9 “	4.3 “	
20 “	....	1.5 “	2.4 “	3.5 “	
25 “	....	1.3 “	2.1 “	3.0 “	
30 “	....	1.2 “	1.9 “	2.7 “	

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[1] Archives d'Electricite Medicale, Bordeaux, July 15, 1899.

This must be modified in certain cases, for instance, where we wish to show the relative position of the vertebræ and a renal calculus or a bullet embedded near the spine. In these cases we would use the number corresponding to a much less thickness of tissue than if, for instance, we wished to show the anatomic relations of the chest. In general, the nearer the objects of chief interest are to the plate, the greater is the distance that the tube must be shifted between taking the first and the second radiograph.

There is required a convenient means of removing the first plate and placing another in exactly the same position, or, according to Caldwell's suggestion, metallic portions of the plate-holder projecting over the edge of the plate and by their image indicating exactly corresponding parts of the two plates. The plates may be pushed into a slot and removed with any movement of patient or stereoscopic plate-holder.

The *tube-stand* designed by Brickner, of New York, serves a very useful purpose in stereoscopic radiography. There is an upright hollow wooden shaft in which plays a counterbalance like a sash-weight of a window. The *sash-cord* is attached to a carrier, which in this way may be raised or lowered, and remains in position without any fastening or unfastening. Through this carrier there passes a horizontal arm which is also adjustable and self-retaining. At the end of the horizontal arm is the tube-holder, adjustable in every direction and secured by heavy screws. There is a scale of inches upon the vertical shaft and upon the horizontal arm, and the tube can be moved a measured distance in either of these directions without fastening or unfastening anything. The motion is made by a rack and pinion effect of friction wheels.

Ripperger's modification of this stand includes a box large enough to enclose the x-ray tube and of material that is opaque to the x-ray. This is an element of safety for the operator.

The same tube-stand or its modification is useful for most of the applications of the x-ray in diagnosis and treatment: It makes it very easy to place the tube in the exact position required; it is also substantial enough in construction to carry a Friedlander shield; and the fact that there is very little metal about it makes the arrangement of the conducting cords an easy matter. With a stand made largely of metal, of course, the conducting cords should not be allowed to touch any but the appointed part of the stand, as otherwise there would be a spark and more or less waste of power and damage to the cords. Whatever be the construction of the stand, the clamp should grasp the tube by its principal prolongation surrounding the cathode stem, and not by the little projection from the tube, which is made for the principal purpose of connection with the air-pump when the tube is being exhausted. Care must always be taken to prevent the patient receiving a spark from the conducting cords or from the points of the tube. There is a disagreeable but not injurious shock received, which would be accompanied by a burn if for any reason the patient were unable to break the contact by an instinctive or reflex movement. Contact with both wires at once would be productive of a very serious shock.

Pigeon's Mirror Stereoscope.—This is one of the simplest, least cumbrous, and best instruments for examining stereoscopic radiographs, prints, or negatives. The plates or prints are placed on two sheets of ground glass while the observer looks directly at the right hand picture, and at the same time sees the reflection of the other picture in a small triangular mirror (Fig. 507, M.) This is made by Radiguet and Massiot.[1]

Stereoradiography Without a Stereoscope.—This process, suggested by Guilloz,[2] consists in making two successive pictures upon the same plate, shifting the x-ray tube the proper distance after the first exposure. A wire net screen is used during the exposures and also for looking at the completed picture.

Stereoscopic Fluoroscopy.—The most practical method is by having two x-ray tubes excited at the same time by an alternating current, and having a synchronous shutter which allows each eye to see the fluorescent screen only during the periods that it is illuminated by the proper tube.

A sufficiently powerful transformer will do this if there are two circuits each made up of an x-ray tube and a ventril tube. The x-ray tubes have opposite polarities.

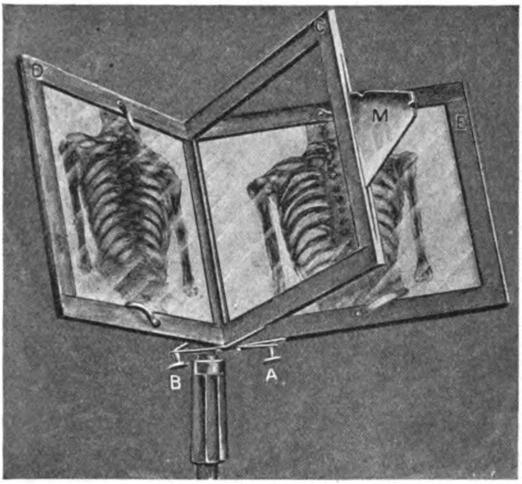

Fig. 507.—Pigeon's reflecting stereoscope for examining radiographs.

Value of Stereoradiography.—Stereoscopic radiography is useful in depicting subjects like renal calculi and fractures of the femur, but for the location of foreign bodies better results are obtained by the comparison of two different radiographs taken at a very much wider angle.

The Nature of the Material Back of the Plate.—In using the ordinary black and orange envelopes a distinct effect is often produced on the plate which is analogous to a reflection from the surface upon which the plate with its envelopes rests. In reality this effect is due to secondary rays caused by the impact of the x-ray upon the material back of the plate. These secondary rays fill the entire x-ray room and are diffused in every direction, and unless prevented by something opaque to them an extraneous effect will be produced on the plate from two sources: First, by secondary rays arising from the direct x-ray

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[1] Arch. d'Electricité Med., April 25, 1907.

[2] Comptes. ren. de la Societé de Biologie, vol. lvii, p. 662, Dec. 13, 1904.

which has passed through the plate and encounters wood or metal or glass, etc., close behind the plate; and second, by secondary rays arising from the x-ray reaching various parts of the room without having passed through the part to be depicted. Imagine a brilliant electric light out in the open air on a dark night and an opaque body like a thick paper-covered volume held so that the light shines vertically upon one cover; we should find that the lettering on the other cover was not lighted enough to be seen. But now take the same brilliant electric light into an ordinary room, and the diffused light from every part of the room will be so bright that the lettering on the shaded side of the volume can be read very well. An analogous condition is produced by the x-ray, but the secondary rays are so much less powerful than the direct rays that they only become a disturbing factor when the direct rays are weakened by passage through thick tissues, and the effect of the secondary rays is increased by the length of exposure required. In taking a chest or a pelvic picture, if there is an irregular backing of wood and metal with, perhaps, an air space, the evidence of this will be found upon the plate, and I have been consulted about such pictures which had proved quite a puzzle to the radiographer. It is my own practice to use a backing of x-ray metal, lead and tin, about $\frac{1}{3}$ millimeter thick, behind the plate but outside of its envelopes. This cuts off any influence coming from behind, and whatever secondary rays are generated upon its surface are in proportion to the amount of x-rays striking it, so that to a certain small extent it acts also to intensify the image on the plate. If only a part of the plate is protected by the x-ray metal backing, the part which rests upon the uncovered wooden table is a very great deal darker than the other, and in some plates shows even the grain of the wood. It is evident that wood either has a much greater capacity for induced x-radiance than lead, or that it is transparent to the secondary rays coming from various parts of the room.

Two plates may be placed on top of each other, both in separate black and orange envelopes, and a picture be made upon both at the same time, and sometimes the picture upon the lower plate is the better. The lower plate receives only about two-thirds as strong an impression from the direct x-ray because the upper glass plate is not nearly as transparent to the x-ray as glass is to ordinary light. The lower plate, therefore, is not as dense as the upper, but the image on it is sometimes clearer because the upper plate often almost entirely cuts off the less penetrating secondary rays arising from the x-ray tube. The x-radiance excited in the thicker tissues, like the liver, is the chief source of indistinctness in radiographs through such parts of the body, and this indistinctness may be somewhat reduced by having the film surface of the plate down, or by using two plates. My experiments with a thin metallic screen over the plate have not thus far resulted in improvement in the image produced. The use of a diaphragm or cylinder to cut off the secondary rays from the x-ray tube reduces this indistinctness very decidedly.

A practical point to be observed is in connection with the perspiration which may be present upon the surface of the part in contact with the x-ray envelope. If this strikes through the envelope it will produce a chemic effect upon the film, resulting in a picture in which the print will be seen spotted with white dots. To prevent such an accident it is well to always have a piece of blotting-paper between the x-ray envelope and the part of the body resting upon it, unless two plates are used face to face in the same envelope.

Marking the Plate for Identification.—Lead or other metallic figures and letters may be placed upon the upper surface of the plate, outside of its envelopes, and at the same time that the radiograph is made an image of these is also impressed upon the plate, and is reproduced in every print made from it. My own custom is to have my name and the serial number of the plate, and sometimes the word "right" or "left." Such a word is necessary in every case in which two symmetric portions appear upon the same plate, like the two sides of the pelvis, or both shoulders, or both knees, unless there is known to be some striking difference which will enable us to identify the two sides. It is possible to be pretty sure that a certain side of the plate represents the right side of the body if we make a practice of having the film-side of the plate uppermost, and have a record of the position of the patient, whether prone or supine. But this calculation would be based upon the assumption that the plate was correctly placed in the x-ray envelope, and when a person is to be operated upon for a stone in the kidney it is necessary that there should be no possibility of error as to which kidney it is that the x-ray picture shows the stone to be in. In the absence of any special metal letters any suitable object, like a key or a coin, may be laid upon the side of the plate upon which rests the right side of the body. A written note to that effect should be made before the exposure is finished. If not made while the plate and the marker and the patient are all in the same relative positions, the identification of the right and left sides of the patient in the picture again becomes a matter of memory and calculation. The letters and figures I use are cut from x-ray metal about $\frac{1}{3}$ millimeter thick. If the plate is film-side up, the letters and figures must be completely reversed when laid on top of the plate in order that they shall appear in their proper relation on the print; but if it accidentally happens that they are not put on in this reversed position, it may later be corrected by printing the picture with the glass instead of the film-side of the plate in contact with the velox paper in the printing frame. I find it convenient to have all the letters of the name pasted in a reverse position upon a card, and to have the single figures pasted upon card-board slips, which fit in a sort of pocket on the name card, together with a slip on which is pasted either "right" or "left." An x-ray plate is like a transparency: if you are looking through from one direction at a picture of two hands the hand with the wedding ring on it may appear to be the left hand, and if you look through the plate in the opposite direction that hand will appear to be the right one. In a picture of the two hands taken upon a plate with the film-side up, the hand with the wedding ring on it will appear to be the left hand; but if the film-side is down, as it usually is in the print, the picture will make the hand with the wedding ring on it appear to be the right hand.

RADIOGRAPHY

In taking a picture by means of the Röntgen ray no camera or lens is required. The sensitive plate, film, or paper is so placed that a shadow falls upon it produced by the interposition of the object to be depicted between the x-ray tube and the sensitized surface. The effect produced upon the plate is the same as that produced by light in ordinary photography, and the plate is subsequently developed by the same processes that are employed with daylight pictures. The background of the picture on the plate is produced by the unimpeded action of the x-ray, the half-tones by the action of the ray but slightly diminished by traversing the flesh, which in thin layers is generally as transparent to the x-ray as glass is to ordinary light; the bones and metallic substances, on the other hand, cast deep shadows, and on those portions of the plate the photochemic effect is but slight. An ideal plate is one in which the images of the bones, and especially of metallic foreign bodies, are nearly transparent, but with fine detail showing the structure of the bones; and the background is dense, almost opaque. A "print," or the finished picture, of which as many as are desired may be copied on sensitized paper from such a plate, shows the bones black with excellent detail of structure, contrasting sharply with the half-tones of the flesh, and the outline of the latter is clearly defined upon the pure white background. Such a picture can be obtained by what I have called a "normal exposure," meaning by that term the equivalent of the conditions necessary for perfect ordinary photographs. With an ordinary photograph the amount of light and shade upon the object, and the amount of light admitted to the camera, and the length of time during which it is allowed to act upon the plate, are all very commonly under complete control. With the Röntgen ray, however, it is only exceptionally that it is possible or desirable to secure all the gradations between opaque density and almost perfect transparency. With the hand and foot a normal exposure can readily be obtained, but with the thickest portions of the body this is entirely impracticable.

The plate is usually contained in an opaque black envelope, and outside of this there is one of orange paper, and thus enveloped it is as safe from ordinary light of moderate strength as a plate in a plate-holder or a film in a camera. These envelopes ordinarily present no impediment at all to the passage of the Röntgen ray and the plate must, therefore, not be kept in or even near the room in which the x-ray is turned on, except during the actual exposure for taking the radiograph. Such a plate in its envelopes may be placed upon a table, the hand or whatever part is to be radiographed is placed upon it, and the x-ray tube placed directly above this at a distance from the plate which bears a distinct relation to the size of the plate and to the thickness of the part to be penetrated. The x-ray is turned on for the proper length of time and the picture has been taken, it being only necessary then either to develop it one's self or give the plate to a professional photographer for development. There are differences between the development required for most x-ray plates and that used by the ordinary photographer whose plates have all had approximately normal exposures. These special points are detailed in the chapter on the development of x-ray pictures.

Some of the factors to be considered in making a radiograph are the *distance* from the plate to the tube, the position of the portion to be radiographed, the degree of vacuum in the tube, the strength of the primary current, the rate and character of the interruptions in the primary current, the self-induction in the primary coil, the presence or absence of spark-gaps between the secondary coil and the tube, and the amount of current passing through the tube. The sensitiveness of the plate or film, the duration of exposure, and the nature of the material back of the plate are also important. It is only by a proper combination of all these elements that the best results can be obtained, and the only ways in which one may hope to improve in technic are first to study the recorded experience of others, and second, to make a most painstaking record of all the particulars in regard to each exposure made by one's self.

The tube ought to be at such a distance from the plate as to produce a nearly uniform amount of photochemic effect upon all parts of the plate. In the case of a little tooth-film, an inch and a quarter by an inch and three quarters, the anode will be practically equally distant from all parts of the film at 9 inches, which is the shortest distance to be recommended for radiography. This distance is measured from the anticathode to the surface of the film. But with a plate measuring 14 by 17 inches, the tube must be about 22 inches away in order that there shall be anything like a uniform action. The action of the *x*-ray diminishes rather more rapidly than the square of the distance, and if the distance from the tube to the center of such a plate were only 9 inches, it is easily seen that portions of the plate 8 or 9 inches from the center would be almost twice as far away from the tube as the center of the plate. The action produced upon the peripheral parts of the plate would, in such a case, be only about a quarter as intense as upon the center.

Again, the distance must bear a certain relation to the nature of the part to be radiographed in order not to produce imperfect or misleading effects, such as distortion. If the portion to be radiographed is comparatively small and can be placed in close contact with the plate, like one phalanx of the finger, the tube may be placed at the minimum distance. But when the object is large and parts of it are at different distances from the surface of the plate, and from the direct line from the tube to the center of the plate, the tube must be far enough away to produce approximately parallel rays. A desirable maximum distance has seemed to be 22 inches. A greater distance would give still less distortion, but would require a longer and stronger exposure; and with a much shorter distance the portions far from the surface of the plate appear unduly magnified as compared with those portions near the plate. This is like the magnified shadow of a hand held near a candle, while if the hand is quite near the wall the shadow is only the natural size.

Diffused Radiation.—Another feature which has a bearing upon the question of distance is the fact that an appreciable amount of *x*-ray radiates from all the different parts of the tube. This is well shown in the picture of a penny right in the shadow of a silver dollar (Fig. 508). In making this the penny was close to the plate and the dollar half-way from the plate to the tube in such a position as to completely exclude direct rays from the focus point, or any other part of the anticathode, from reaching the part of the plate on which the penny rested. Rays from the walls of the tube passed in straight lines and met at an angle behind the dollar and there produced a picture of the penny. That it was this and not partial transparency of the metal disk is shown by the other picture in which the dollar is nearer to the plate, and in which the image of the penny cannot be seen. This is an observation which may be confirmed by means of the fluoroscope. Its practical value consists in the knowledge that the image of anything at a distance from the plate is sure to be more or less hazy in consequence of this penumbra, and, of course, the nearer the tube is the greater is the angle which the rays from its walls make with its focus rays; blurring of the image which results from having the tube too near when the point of interest is not in absolute contact with the plate.

An example of the *blurring* from diffused radiation is seen when the hand with outstretched fingers is held outside a window-shade not exposed to direct sunlight. When the hand is pressed against the shade its shadow is clearly visible with its outstretched fingers and the spaces between them, but when the hand is held a few inches outside of the cloth its shadow cannot be distinguished.

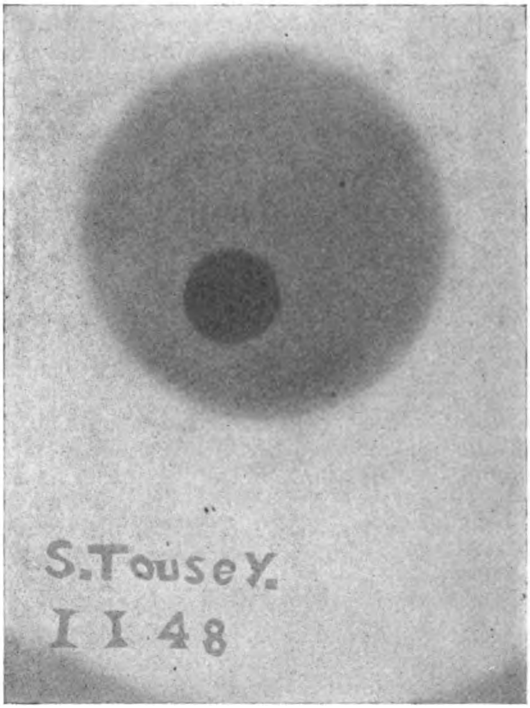

Fig. 508.—Radiograph of penny produced by secondary rays in the shadow of a silver dollar.

The diffused secondary x-rays passing through an object at a distance from the plate would not only give a blurred image of their own but would also blur the image due to the direct rays.

The author cannot help feeling that the *secondary rays arising in the tissues* are partly the source of our ability to make radiographs, such as those of the frontal sinus, at all. Some cases of his have shown two or three times as great discoloration of the photographic plate at the image of the frontal sinus on the sound side as upon the side where a subsequent operation revealed the presence of only one or two teaspoonfuls of pus. The direct rays passing through the entire thickness of the scalp, skull, and brain would encounter only a very small fraction of greater total density on one side than on the other. This would not fully account for the great visible difference in the resulting images.

If we suppose that every particle of matter in the head is emitting secondary rays, we should at once expect that differences in density of the skull at various points would arrest different proportions of the radiance from within, and show a difference in the radiograph.

This explanation is rendered all the more plausible by the consideration that secondary rays have comparatively little penetration and, consequently, it is only the radiation from the portion near the plate that is concerned in the production of the image. A difference of a certain fraction in the density of the skull at the part nearest the plate would make a difference of almost as great a fraction in the total resistance encountered by the secondary rays reaching the two parts of the plate. It is true that secondary rays arise from this part of the skull itself, and, doubtless, in proportion to its density, and this aids in the production of a good image if the plate is very near. Secondary rays would also arise from the skin in proportion to the rays, direct and secondary, which reached it, and would tend to reinforce a clear image upon a plate in contact with it.

This is given as the author's theory, not as an established fact.

If parallel rays could be obtained from an x-ray tube this blurring of the image of parts at any appreciable distance from the plate would be partially prevented, and, furthermore, the image would be of exactly the same size as the original object, no matter how far from the plate it was, provided that it lay in a direction parallel to the surface of the plate, and that the rays fell vertically upon the plate. This condition of parallel rays cannot be fully accomplished, the x-rays can neither be reflected nor refracted, and the major part of them diverge from a very small point in the center of the tube, so that in a regular x-ray picture the divergence of the direct rays from the focus point on the anticathode must produce magnification of the image in proportion to the relative distance of the object from the plate. The actual size of the object can usually be determined, closely enough for all practical purposes, by a simple calculation based upon the size of the image, and the relative distance from the object to the plate and to the tube. For instance, if the object were just half-way between the anticathode and the plate, the image would be twice the diameter of the actual object. Of course, in most cases this is only approximate, since we usually do not know the absolute distance. For the few cases in which it is necessary to determine the exact size of an object, for instance, the heart, resort must be had to the orthodiagraph described at length in the chapter on Fluoroscopic Examination.

Albers Schönberg's Compression Cylinder.—The compression cylinder of Albers Schönberg makes no attempt at orthodiagraphy, but it is a step in the direction of eliminating blurring when the object is at a distance from the plate. It does this by cutting off many of the extra rays arising from various parts of the tube, and allowing principally the direct rays from the focus point to reach the plate. Of course, these are the original divergent rays and the image is just as much magnified as if the cylinder were not there, but the claim is that the image is more clearly defined. The compression cylinder itself is of brass, lined with lead in order to be opaque to the x-ray, and is about 4 inches in diameter and about 5 inches long. It forms part of a complicated apparatus by means of which one open end of the cylinder may be pressed against the abdomen or any other part. It produces in all cases fixation, and in some places, like the abdomen, reduction in the thickness of the tissues to be penetrated by the *x*-ray. At the other open end of the cylinder the *x*-ray tube is held in position by another part of the apparatus. The pictures are, of course, limited by the size of the cone of rays which passes through the cylinder. The extra rays are not all cut off by any manner of means. All those emanating from a part of the tube 4 inches in diameter are free to take part in the production of the picture. It is certainly an excellent device for cases in which a small picture is sufficient, and in which it is possible to so judge of the position of the object of

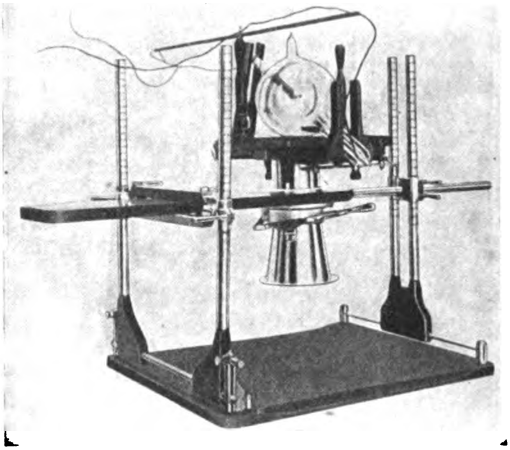

Fig. 509, A.—Compression diaphragm. (Kelley-Koett Company.)

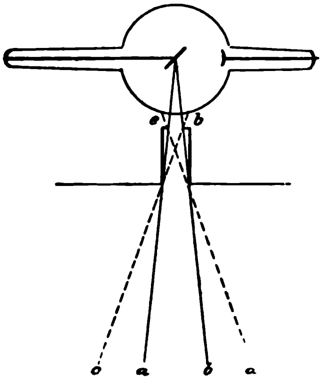

Fig. 509, B.—Dotted lines are secondary rays which would pass through an ordinary diaphragm, but which are arrested by the walls of the cylinder.

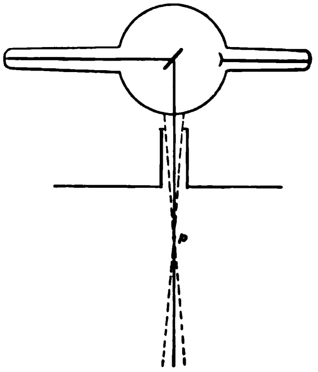

Fig. 509, C.—Showing slight blurring of the image of a point by secondary rays when a cylinder and diaphragm are used. (Small letters in 509, B and C, explained on page 756.)

interest as to direct the cylinder accurately enough to include the object of interest in a picture only a little over 4 inches in diameter.

Reasons for Abandoning Radiating Cellular Diaphragm.—In the first edition of this work the author's radiating cellular diaphragm was described. It has been found, however, that it was necessary to use the fluoroscope to so accurately place the x-ray tube so as to cast only linear shadows of the wall of the central funnel. This involved a dangerous exposure of the operator and caused the use of the apparatus to be given up.

Radiographs through thick portions of the body often show the evidence of sufficient density of x-ray effect upon the plate to produce a picture if there were only also contrast and detail. These are lacking, largely because of the secondary rays which arise in the tissues of the body; and the harmful effect of these secondary rays upon the quality of the picture may be very much reduced by diaphragms and cylinders, which cut out the secondary rays from the tube. This is really one of the most important facts in Röntgenology.

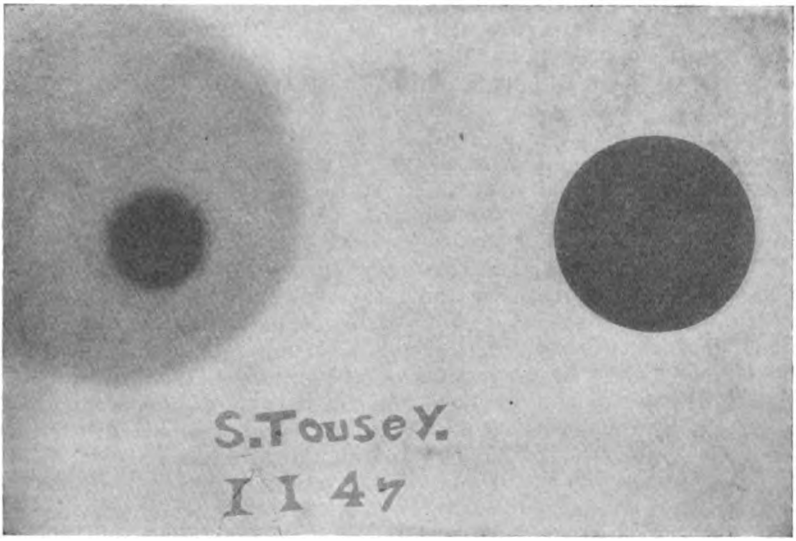

Fig. 510.—Radiographs of dollar and penny, showing secondary rays: A, Dollar 5 inches from anticathode, its shadow very faint because secondary rays from the x-ray tube reach the space behind it and show a clear image of the penny, which is close to the plate; B, dollar close to the plate and casting a dense shadow in which the penny cannot be seen. A and B made at the same exposure.

A tube so constructed and actuated by such a current that it gives out the smallest possible amount of secondary rays is most desirable, if it must be used for radiographing thick objects without a diaphragm or cylinder. This element and the right degree of penetration and the right intensity of radiance are the difficult factors in successful radiography. The proper length of exposure is a matter which is easily learned by experience and may be closely approximated by referring to the table on p. 767.

My judgment of the value of all such diaphragms and cylinders is that they are vitally necessary in so far as they protect the operator and all parts of the patient except the portion that is to be depicted; and that they add so greatly to the clearness of definition as to be extremely desirable for radiographing any thick portion. Their use renders radiography of the frontal sinus an easy matter, with correct technic, whereas, without a diaphragm or cylinder, it is practically impossible to secure a good anteroposterior radiograph of this region.

The extra rays from the *x*-ray tube do not appear to have great power, but they give origin to secondary rays in the tissues which differ in no respect from the secondary rays originating in the tissues under the influence of the direct focus rays.

Diaphragms and cylinders, by cutting off most of the extra rays from the tube, very greatly reduce the blurring of the image due to secondary rays arising in the tissues.

The objection that a shield of any kind surrounding the *x*-ray tube gives rise to secondary currents and an electrostatic condition tending to cause rapid hardening of the tube does not prove to be well founded. The author uses the Ripperger shield constantly for therapy or radiography and experiences no difficulty from this source.

Any opaque box, used to contain the tube and protect the operator from the deleterious effect of the *x*-ray, must be provided with means for connecting both the anticathode and the accessory anode, or either one separately, with the positive pole of the induction-coil; and for connecting the cathode with the negative pole of the coil.

The Influence of Tissue through Which the Rays Pass.—Every substance impinged upon by the *x*-ray, whether transparent to it or not, diffuses a certain amount of radiance in all directions, and the tissues of the body have in this way a certain radiance of their own. This is one element in the production of an indistinctness in the image of parts of the body at a distance from the plate; and there is no remedy for this particular defect. On account of this fluorescence of the body it is a wise precaution to have the patient remain motionless for a few seconds after the *x*-ray is turned off before removing the plate.

After all that has gone before, it is easy to understand that the portion of chief interest in every picture should be brought as close to the plate as is practicable. This is in order to secure the clearest possible picture of the object, but the rule is applied with discretion. In taking a picture to show a portion of the brass shell of a cartridge which had been in the calf of the leg for four months, our purpose would be more to determine how deeply it was embedded in the flesh than to get a clear image of the fragment. Consequently, the picture would be taken in profile instead of in a direction which would bring the fragment some inches nearer the plate. The result is a more useful but less beautiful picture.

Again, at a distance to one side of the direct line the image would appear longer than natural in that particular direction, while its transverse measurement might be about natural. This is analogous to the lengthened shadows cast by the setting sun. The distance must, of course, be so great that with the requisite strength and duration of application there shall not be the slightest danger of an *x*-ray burn. So in taking a picture through the entire thickness of the body the distance from the tube to the plate must be correspondingly greater than in radiographing the hand. With the author's board compressor the thickness of the body is reduced 2 or 3 inches, and the tube may be

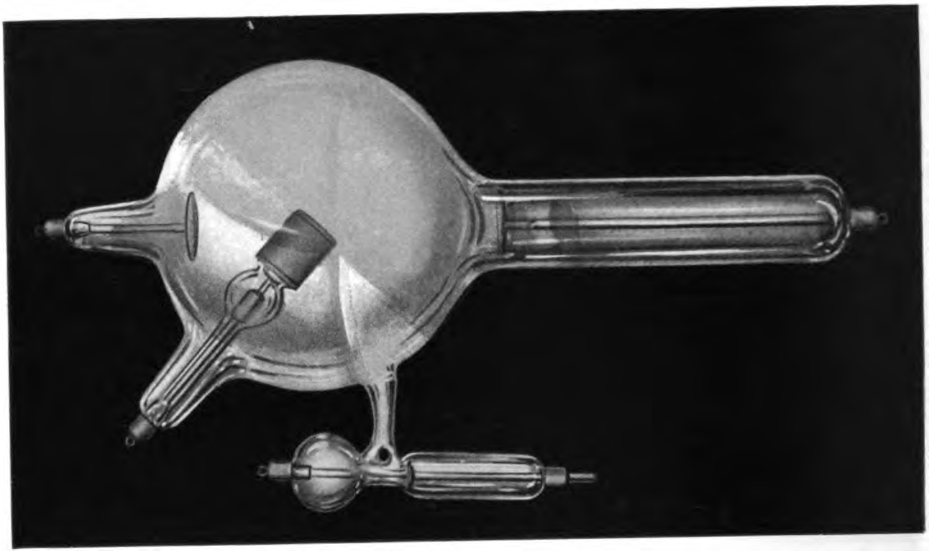

FIG. 2.—X-ray tube in operation. Too high a degree of vacuum.

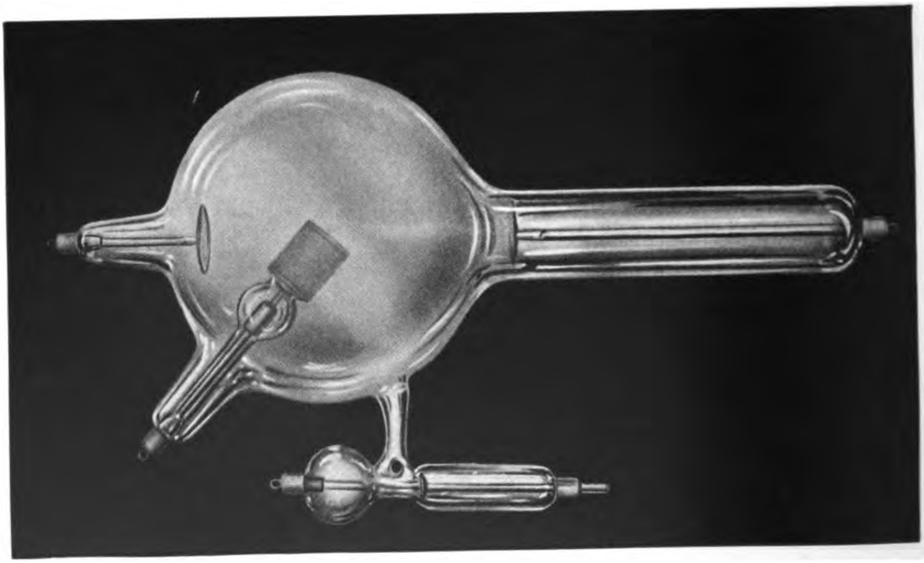

FIG. 1.—X-ray tube in operation. Vacuum too low.

brought that much nearer the plate and still be at the same distance from the surface of the body, so that, generally, the 22-inch distance from the plate works well in this case.

The **degree of vacuum in the tube** is a matter of prime importance. For the majority of cases it should be so low that the *x*-ray will penetrate but one to five layers of lead foil in the author's fluorometer, 100 square inches weighing an ounce; and that the resistance of the tube is not sufficient to back up a spark of 2 inches. A tube in which the vacuum is altogether too high is sometimes spoken of as a hard tube and it is one in which the partial vacuum in the tube is too nearly a complete vacuum. It contains too little gas or air. Such a condition produces snapping and sparking about the electrodes of the tube, and if too strong a current is turned on the tube may be punctured. This happens by a spark bursting through the glass close to the cathode and leaping across the air outside the tube to the entrance of the positive wire at the other end of the tube. The sparking and possible puncturing are due to the great resistance to the passage of the current across the space between the cathode and the anode in the unduly rarefied gas in the tube. Another effect from such a tube is the backing up of a long spark. The wires from the two poles of the secondary coil pass to the two poles of the tube and all the current is expected to pass through the tube, but if the resistance in the tube is greater than the resistance in the air-space between the two poles of the coil, the current, of course, will take the path of least resistance and if strong enough will spark across between the two poles of the coil. In every *x*-ray outfit movable metallic rods should be attached to each pole of the coil, and by turning these toward each other we can determine the distance across which a spark will pass between the two poles of the coil. Two factors enter into the production of this distance: one is the strength of the current, and the other is the resistance to the passage of the current through the tube. With a very weak current, of course, we could not get a long spark across the space between the poles of the coil even if the resistance in the tube were very great, or if the tube were disconnected from the coil entirely. In the latter case, of course, the only path open to the current is across the space between the poles of the coil. This factor, the *strength of the current*, is adjusted in the simplest manner, just turning the rheostat up until the amperemeter shows that the necessary 3 to 6, or 9, or, in some cases, 15 and even 30 amperes are passing through the primary coil.

The other factor is the *resistance in the tube* and this is measured by turning on a standard strength of current, say 6 amperes, and approximating the points connected with the two poles of the coil until a spark passes between them. If 6 inches is the greatest distance at which this discharge will take place, the tube is said to back up a 6-inch spark, or to have a resistance equal to a 6-inch parallel spark-gap. A tube with a resistance of 6 or 7 inches would be too high for most kinds of radiographic work. Usually such a high vacuum and consequent high resistance imply great penetration by the ray, and in some cases this is desirable, as in radiographing the roots of teeth, showing the teeth right through the jaw, and even the pulp canals in the roots of the teeth. Still even here a moderately low vacuum is often better, as it gives so much better contrast.

With an induction-coil the spintremeter, for actually testing the length of spark the tube will back up is necessitated by the presence of the inverse discharge, which, while usually eliminated, may occasionally invalidate the milliampere reading as a criterion of the degree of vacuum in the x-ray tube.

With a static machine the voltmeter is a useful gauge, providing a standard series gap is used and the usual power turned on and the machine giving its accustomed output. The spintremeter is not especially suitable for use with the static machine.

With an unfluctuating generator no spintremeter is required, as the resistance of the tube is shown at once by the consideration of the volts backed up and the number of milliamperes transmitted. This reading, and the necessary regulation to make it right, had better be made with low-current values, which do not overheat the tube and act slowly enough to permit of accuracy. It will usually be found that 40 kilovolts and 5 milliamperes indicate a degree of vacuum suitable for many Röntgen-ray purposes. Turning on more power the current values will probably become 62 kilovolts and 25 ma., and with a great deal more power 90 kilovolts and about 50 ma.

With a transformer also the spintremeter may be dispensed with. The number of milliamperes transmitted by the x-ray tube, with a given ratio of transformation and adjustment of rheostat with a given strength of primary current, are a sufficient guide. As an example, it may be stated that with rheostat button No. 11 of the Waite and Bartlett transformer a current of 35 milliamperes indicates a comparatively hard tube suitable for making a radiograph of the bismuth meal in the stomach in about one-fifth second with an intensifying screen. Other buttons of the rheostat would send 50 milliamperes or more through a tube in the same condition of vacuum. It would be well for everyone using a transformer outfit to determine once for all the adjustment of rheostat and ratio of transformation for a weak current which will give a reading of one-tenth the current to be sent through the tube when the usual radiographic current is turned on. The weaker current may then be used in regulating the degree of vacuum in the tube.

Another method in which the vacuum in the tube is estimated is by determining the *degree of penetration* of the x-ray with about the usual amount of current.

1. With an excessively low vacuum there would be no light visible at all in the fluoroscope.
2. With what is ordinarily regarded as a very low vacuum the fluorescent screen in the fluoroscope is lighted up, but if the hand is held up in front of it the entire hand appears black and opaque, and, of course, the bones cannot be seen through the flesh.
3. With the regular low vacuum the bones show beautifully, almost black, the flesh clearly defined both from the much darker bones and from the brilliant light of the background.
4. With a high vacuum the flesh and bones are almost equally transparent and present very little contrast. Twisting a watch chain around the hand, the links are seen so clearly through the bones that you cannot distinguish between those which are behind the hand and those in front.
5. An excessively high vacuum shows some light upon the screen and a grayish outline of the hand with very little evidence of the bones.

To the experienced eye there is all the difference in the world between the poor image of the hand shown by a tube which is so excessively high that it is not giving out any effective x-ray at all, and a tube in the contrary condition which is giving out a flood of x-ray producing brilliant photochemic effects, but not pitched to the rate of vibration requisite for good penetration. In the case of the tube which is a great deal too *high* the tube shows very little luminosity, it is not sharply divided into a dark and a light hemisphere, and the dark portion is blotched over with patches of greenish light moving like a liquid. The resistance is high. The fluoroscope shows very little x-ray and a very poor but not black image of the hand. In such a condition a tube is worthless, but lowering the vacuum will effect a wonderful transformation.

The milliamperemeter, which measures the quantity of current passing through the tube, shows a decided increase in current when the vacuum becomes low, and gives a useful warning of the approach of any great drop in vacuum during the exposure for a radiograph. The same diminished resistance in the tube is made evident by an increased amperage in the primary coil. In all these cases the same amount of electromotive force is behind the supply current and diminishing the resistance in any part of the apparatus increases the quantity passing through every part of it.

A tube that is so *low* as not to give any x-ray visible in the fluoroscope seems to be filled with bluish or purple light (Fig. 435). There may be a blue streak extending from the center of the cathode to the focus point on the anticathode. Such a tube may look almost as if it had been punctured. In some extreme cases it is not possible to raise the vacuum to the x-ray producing point by any means short of sending the tube to the manufacturer to be reëxhausted with an air pump; and, of course, this is always necessary in case of a puncture. In many cases, however, the vacuum has temporarily been reduced to too low a level by gases generated from heating the metal parts by too strong or too prolonged use or by incautious regulation of the vacuum, and when the tube has cooled these gases will be found to have been reabsorbed.

The *Villard osmo-regulator* on certain x-ray tubes may be used to raise the degree of vacuum (p. 734), or the vacuum may be raised by turning the current on and off for short periods, and this may take five or ten minutes' work. Other tubes come up quite rapidly if a fairly heavy current is turned on for a few minutes, and others, especially the heavy anode Gundelach tubes, will come up if a reverse current is run through them. With some of the Müller tubes there is a raising device, consisting of a side tube communicating with the main bulb and containing a spiral of platinum wire; the positive wire may be connected with this instead of with its regular attachment, the negative wire being in its normal position; and the normal current turned on. The current passing through the platinum spiral causes absorption of gas to take place, presumably by throwing off molecules of metal which absorb molecules of gas; and in that way the vacuum is raised in a very short time. A special arrangement for raising the vacuum of a tube is not by any means necessary. The vacuum inevitably becomes higher the more times a tube is used, and each time it is used it is necessary to spend more time reducing it to the proper degree.

To Raise the Vacuum of an x-Ray Tube Without a Regulator.—Connect the accessory aluminum electrode with the cathode and use a weak current. The connections are shown in Fig. 511. With reasonable care it will not be reduced too low, either during the process of regulation or during the exposure for taking the picture. Hence, the vacuum will seldom require raising and then only to an extent which can be produced by operating the tube for a minute or two. The sudden dropping of the vacuum of a tube during operation with a heavy current is due to overheating of the metallic parts, and liberation of molecules of gas which had been held in a state of condensation. This state of condensation is of great importance in the manufacture and manipulation of *x*-ray tubes. The material known as spongy platinum, the pure metal precipitated from a solution of one of its salts, will absorb and hold condensed in its pores three hundred times its own volume of hydrogen gas. This compression, of course, is accompanied by the production of heat, and one of the apparatus of a chemical laboratory before the discovery of matches was based upon this fact. Dobereiner's lamp consisted of a bottle containing iron filings into which a few drops of sulphuric acid were poured, the hydrogen gas, which was evolved, escaped by a glass tube at the tip of which was a bit of spongy platinum. Sufficient heat was produced by the condensation of the hydrogen in the spongy platinum to raise the metal to a red heat and set fire to the jet of gas. The flame, thus produced, was used for exactly the same purposes that matches are now. There is now on the market an attachment for the self-lighting of Welsbach gas-burners, consisting of two little bells suspended over the burner. Each bell contains a bit of spongy platinum which becomes hot from absorption and condensation of gas and in less than a minute the gas ignites.

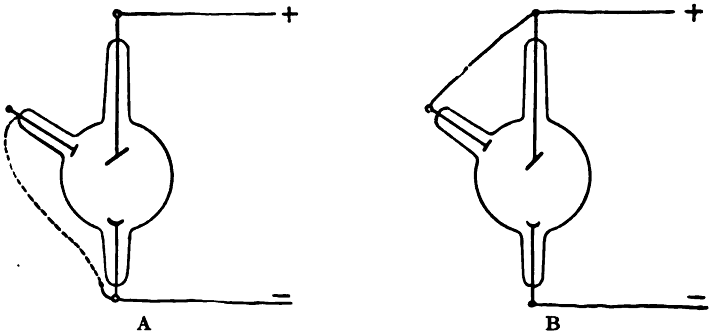

Fig. 511.—A, Raising the vacuum in a tube which has no regulator; B, lowering the vacuum.

In using a heavy current, or even a moderate one for a prolonged exposure, the author has found it very advantageous to watch the tube closely and to turn off the current for a while at the approach of this condition of excessive lowering of the vacuum from the sudden liberation of gas by overheated metal. It is never difficult to see that this is coming. The milliamperemeter sometimes registers an increased current from the lessened resistance in the tube, and at other times a sudden drop to zero or to an excessive milliamperage in a reverse direction occurs. The interrupter takes on a different sound, corresponding with the change in the current, and a blue or steel gray color develops between the cathode and the anticathode. The current is turned off at this stage and the tube allowed to cool, and the exposure can then be continued. Of course it is necessary that the patient and all the apparatus should remain absolutely still. In this way a good picture may often be secured with an exposure divided, if need be, into three or more portions. If the current, on the other hand, is kept turned on at the same rate after the vacuum takes a sudden drop the balance of the exposure counts for nothing, and if unduly prolonged may injure the patient. Looking at a tube in such a condition as this you may not even be able to see the bones in your hand.

In *making x-ray tubes* it is not by any means necessary that they shall contain any particular gas. Ordinary air seems as good as anything, though some manufacturers place a little phosphorous acid inside the tube and vaporize it by heat, and others use different gases. In exhausting a new *x*-ray tube, or one which has been sent to have a puncture repaired, or has had to be reëxhausted for any other reason, a current of electricity has to be passed through the tube practically all the time that it is on the pump. This is because the simple application of an air pump would not remove the molecules of gas held in a state of absorption by all the different metallic parts inside the tube. These have to be liberated by the action of a current, and this must be passed through all the different parts of the tube, including the regulators, and it is not unusual for the process to take one or two entire days. The result is a tube containing so few molecules of gas that the vacuum will not fall below the line with ordinary care. The *line* has reference to the condition in which the presence of *x*-ray is indicated by fluorescence in one hemisphere of the tube, separated by a distinct equatorial line from the dark hemisphere (Fig. 512). The opposite condition is shown

Fig. 512.—*X*-ray tube showing proper "line" of demarcation between the illuminated and the dark hemispheres.

in Fig. 513. To prevent a brand new tube from being blackened it has, of course, been exhausted while only a moderate current is turned on, and may still contain imprisoned molecules of gas which may be liberated the moment a powerful current is turned on. For this reason a tube is hardly ever to be used for radiography until it has been *trained* by using it several times for treatments. At the factory during the time that the tube is on the pump and a current of electricity is running through, the tube is prevented from becoming blackened by two facts: first, the current is not very strong, and second, the presence of the secondary anode has a wonderful effect in preventing this. This beneficial effect is produced even when the anode and anticathode are connected by a wire passing between their points outside the tube.

The *blackening* which always takes place in an *x*-ray tube which has been used for any length of time is due to metallic particles driven off of the anticathode by the force of the bombardment of molecules to which it is subjected. It impairs to some extent the efficiency of the tube and cannot be entirely removed even by washing out the bulb with hydrofluoric acid.

Two different kinds of *deposit* occur on the inner surface of an *x*-ray tube; some tubes develop a dull black deposit which interferes decidedly with the efficiency of the tube; others show a purple discoloration of the glass which does not interfere with the quality and intensity of the ray produced by the tube, but such a tube, on the contrary, is often a splendid one.

Generally speaking, the lowest vacuum which will produce a brilliant light in the tube is the best one for radiography, and this will, with most coils, correspond to a resistance somewhat less than 2 inches and to a penetration of about one thickness of lead-foil. This would be the best for the hand or foot. A very slightly higher vacuum would be better for the knee or elbow and one of about 2¾ inches resistance would be best, and for the body about 3 inches resistance. With the powerful current required for pelvic pictures even as low a vacuum as this produces a penetration of five or six thicknesses of lead-foil; No. 5 or 6 Benoist.

Testing the Quality of the x-Ray.—The author very strongly deprecates the *use of the hand for testing* the quality of the *x*-ray from a tube. Everyone who habitually uses his hand for this purpose will, sooner or later, develop a painful and very probably a disabling and disfiguring inflammation of the skin of the hand. A considerable number of operators have suffered the loss of fingers or hand from such a cause, and one experimenter with the *x*-ray, who was not a physician, is reported to have had chronic inflammation from this cause which subsequently was the seat of cancer, which ultimately produced a fatal termination, but we have not learned whether there was an hereditary predisposition or not. At all events the *x*-ray injury appears to have been an exciting cause of the trouble. Of course, it is necessary for the operator to be thoroughly familiar with the fluoroscopic appearance of the hand and all other portions of the body, but no part of the living body should be used for the daily and hourly testing of the *x*-ray.

The author's own *fluorometer* consists of a thin board measuring 8½ by 12½ inches with a handle in the middle. Its major portion is covered by *x*-ray metal to protect the hands and face of the operator, while a strip about 4 inches wide extending across one end is covered with tin-foil, weighing an ounce to a hundred square inches and varying

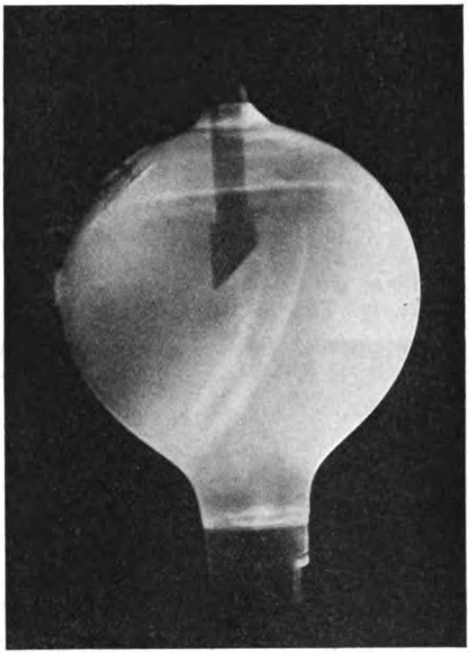

Fig. 513.—X-ray tube not showing a good "line" of demarcation.

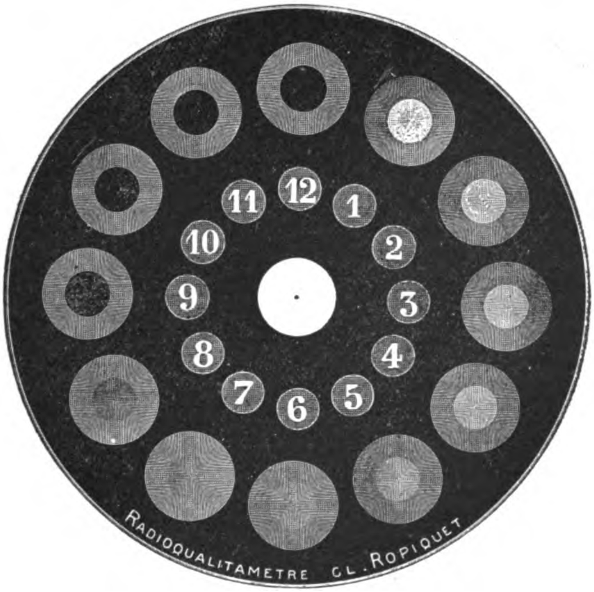

Fig. 514.—Benoist's improved radiochromometer. Appearance with rays No. 7.

from one to ten thicknesses. Transversely across these different layers extends a strip of heavy x-ray metal 1½ inches wide with a large number of perforations at irregular intervals. In using this for testing the vacuum in a tube the x-ray metal and tin-foil completely protect the hands and face from the x-ray. The fluorometer is held in front of the tube by one hand, while in the other the fluoroscope is held between the fluorometer and the operator. Looking into the dark box of the fluoroscope one can at once judge of the brillance of the light by the appearance of the screen where it projects beyond the fluorometer, and the degree of penetration is determined by noting the number of sections of the fluorometer through which the light passes and through which the perforations in the x-ray metal can be seen distinctly.

The number of thicknesses of tin-foil through which the perforations in the heavy x-ray metal are visible is the number by which the degree of vacuum is designated. This is No. 10 in Fig. 515 and No. 4 in Fig.

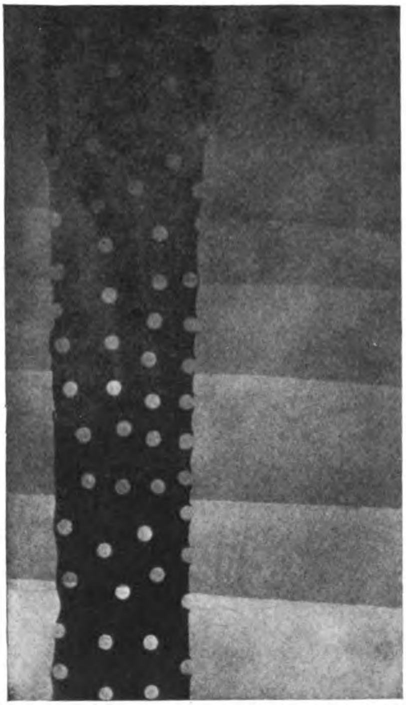

Fig. 515.—Author's fluorometer. Appearance with rays No. 10.

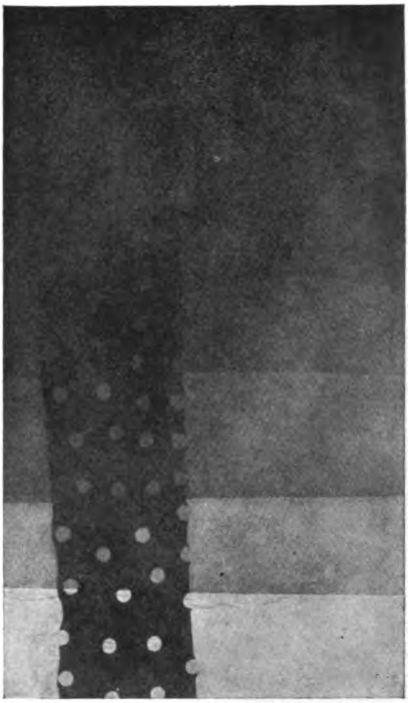

Fig. 516.—Author's fluorometer. Appearance with rays No. 4.

516. Under the usual working conditions the number of inches of resistance is about half the penetration number indicated by my fluorometer.

In *Benoist's radiochromometer* (Fig. 519) the degree of vacuum in the tube is indicated by the thickness of aluminum which the rays will penetrate. There is a central disk of silver, 0.11 mm. thick, surrounded by sectors of aluminum numbered from 1 to 12 according to their different thicknesses in millimeters. When the aluminum section 5 millimeters thick casts the same depth of shadow on the fluoroscope screen as the silver disk, the tube is said to be giving out No. 5 rays and is a tube of medium penetration. A hard tube, on the contrary, gives out No. 7 or 8 rays. It was No. 3 in Fig. 520.

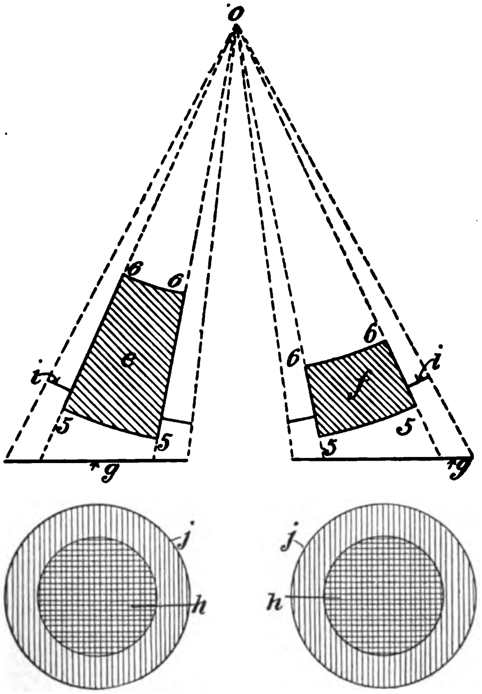

Fig. 517.—Benoist's improved radiochromometer. The different sections, such as *e* and *f*, are inclined toward the anticathode *o*. Each circular image shows an outer zone of silver and an inner disk of aluminum. The shadows of neither overlap, as is the case in Fig. 518.

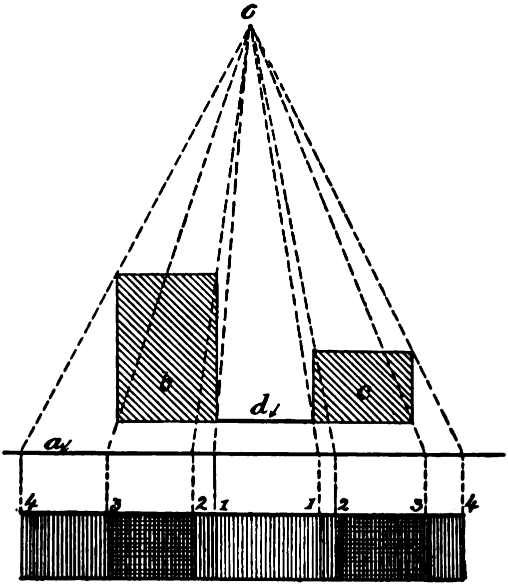

Fig. 518.—Wrong construction of Benoist's radiochromometer. The shadows of the silver and aluminum overlap, so that in one part there is only silver, in another only aluminum, but these are not side by side for comparison, but are separated by a zone of combined shadow of silver and aluminum.

In *Walter's radiometer* there is mounted on wood a thick lead disk with eight holes, which are covered by sheets of platinum, of a thickness of 0.005, 0.01, 0.02, 0.04, 0.08, 0.16, 0.32, 0.64 mm., arranged zigzag so that no two of about the same thickness are near each other. With the screen we see only one lighted circle when there is the lowest degree of vacuum producing any *x*-ray; and with the hardest tube we can see light in all the circles.

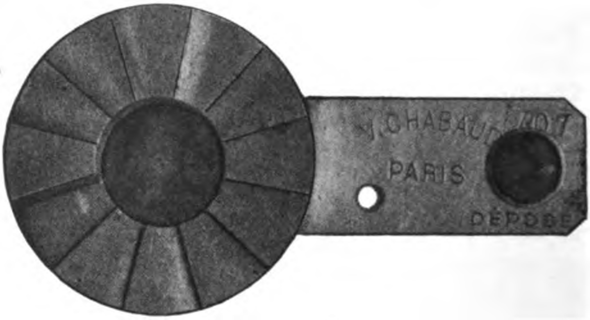

Fig. 519.—Benoist's radiochromometer.

*Villard's radioscleromete*r is an important instrument for measuring the degree of penetration. The *x*-ray shines through a silver disk upon one quadrant of an electrometer and through an aluminum disk upon the other quadrant. The quadrants are charged by a source of uniform potential such as the direct 110-volt electric-light circuit. Ionization

Fig. 520.—Radiograph of young sparrow. Benoist's radiochromometer showing rays No. 3.

of the air by the *x*-ray results in its becoming a conductor and in a reduction in the difference in potential between the two quadrants and a change in their relative position which produces movement of the hand on a dial. The latter part of the apparatus looks like the dial of a milliamperemeter and is graduated in figures, which indicate the same penetration as the same numbers of the Benoist scales. The deviation is independent of the intensity or quantity of the *x*-ray. It depends upon the relative amount of rays passing through the aluminum as compared with that passing through the silver disk.

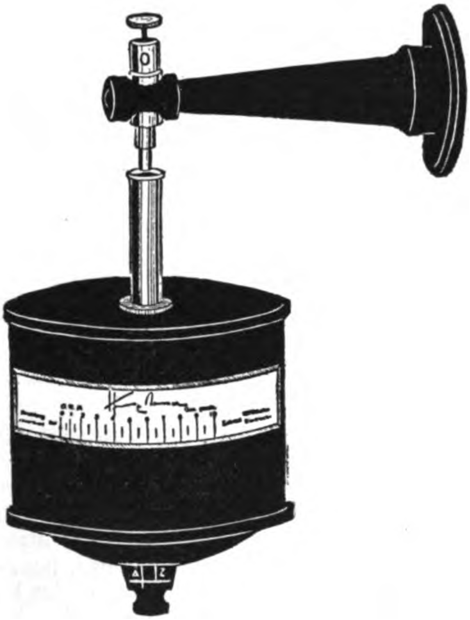

Fig. 521.—Heinz-Bauer qualimeter.

Fig. 522.—Plate marker.

The Heinz-Bauer qualimeter is in effect a voltmeter applied to the cathode terminal of an induction-coil or transformer. The graduations correspond to different degrees of penetration in the *x*-ray produced.

Degree of Penetration.—A brilliant radiance is a necessity for every radiograph, but the degree of penetration is an independent factor and is varied to correspond with the thickness or density of the part to be radiographed. The length of spark which a tube will back up is a most valuable indication of the condition of the vacuum in the tube and of the penetrating quality of the light. A complete change in the degree of vacuum during the exposure would, of course, render the remainder of the exposure useless or possibly deleterious. It is to be guarded against by watching the appearance of the tube both with the naked eye and with the fluorometer, as well as the two meters which show the amount of current passing through the primary coil and the amount passing through the tube itself.

Some tubes become high after the current has been turned on a little time, and when this is very marked it is rather a worse fault than the other. A tube which has a tendency to become low by the evolution of gas may be coaxed along at a uniform degree of vacuum by several short exposures so as to get the full time with a powerful current. But with the other kind of a tube you either have to resign yourself to an increasingly high vacuum or else stop and regulate the vacuum in the tube. This may take several minutes and the effect in such a case is only momentary. An automatic regulator (Queen) may in some cases be set so as to keep the vacuum from becoming too high.

To Lower the Vacuum in a Tube Without a Regulator.—Connect the aluminum accessory electrode to the anticathode and use a strong current. The connections are shown in Fig. 511, B.

The vacuum of a tube which has no regulator may be lowered by heating the tube gradually with an alcohol lamp, not, of course, while the current is on; or the tube may be boiled in oil for half an hour.

A non-regulating *x*-ray tube which has become hard from exhaustion of the gaseous contents through use may return to its original degree of vacuum if it is laid aside for a certain number of days or weeks, or the same result may be obtained by baking the tube in an ordinary oven at a temperature of three or four hundred degrees Fahrenheit. In either case molecules of gas are liberated from the metallic parts of the tube and the deposit on its inner surface by which they had been absorbed.

The *regulating devices* for reducing the degree of vacuum form the distinctive features of the different types of *x*-ray tubes and are described on pp. 734 to 737.

Different Results from High and Low Tubes.—The difference between a radiograph taken with a high and one with a low vacuum is chiefly that the low vacuum gives greater contrast between portions having different densities; while the high degree of vacuum sometimes gives better definition.

With a static machine a tube is required to have a very much higher vacuum than with a coil, but the use of the static machine in radiography is considered in another section.

We often hear the statement that a picture can be made in a shorter time with a high than with a low vacuum, but, coupled with this statement, we usually find indications that the observer does not discriminate clearly the lack of effect due to the absence of intensity or brilliancy and the lack of penetration due to a low vacuum in its strict sense. A low vacuum, of course, is a condition in which there is a large amount of gas in the tube. There must be an appreciable amount of photochemic effect produced on a sensitized plate by the x-ray passing through a portion of the body in a certain period of time in order to make a picture at all. In order to make a good picture the x-ray must be of such a quality that substances of very slightly different densities will arrest it in a sufficiently varying degree to show the outline and structure of the various portions to be depicted. With a high vacuum this selective absorption, to quote Dr. Cole, is almost absent. Even with as easy a subject as the hand, the contrast between the flesh and the dense bones is very slight, and in radiographing a small renal calculus of low specific gravity, the shadow of the column of tissue including the calculus differs very slightly from the adjacent columns. The difference in the density of the two areas is as slight as if they were columns of water to one of which a pinch of calcium salts had been added. The difference may be shown by a ray of the proper character, but not by one which will penetrate ten thicknesses of lead-foil without appreciable absorption. As Dr. Codman says, a radiograph is a chart of the different densities of the parts depicted.

The *thickness and density of the part* have a very great bearing upon the length of exposure and the intensity of the radiation required. Generally speaking, in order to produce a good picture, the tube must give a powerful enough ray to enable us to see nicely through the part with the fluoroscope. Almost everywhere the radiograph will show only the same things as the fluoroscope, but show them better. With practice it becomes an easy matter to judge of the degree of vacuum, strength of current, length of exposure, and all the other factors for any portion of the body without making a preliminary fluoroscopic test. The lungs are almost transparent and pictures of the chest can be made with apparatus hardly strong enough for a pelvic picture. Up to the year 1906 the x-ray in one of the largest hospitals in New York was produced by a static machine with which it required eight minutes to take a picture of the chest and with which it would have taken forty minutes or so for a hip-joint. In these days, of course, such a length of exposure would be prohibitory. While the weak radiation might very well produce no bad effect upon the patient's tissues, the length of exposure required would occasion anxiety on the part of the patient, who, of course, has heard of x-ray burns and who may have heard of the practicability of taking pictures of the hip in from ten to one hundred seconds. The same apparatus, of course, will take a picture of a hand in quite a reasonable length of time. Bone is very much less transparent to the x-ray than flesh and the teeth are still less transparent. As we shall see on another page there is no difficulty at all about making a picture showing the roots of the teeth right through the jaw-bone, and what we consider a good radiograph shows even the entire nerve or pulp canal in the tooth and its roots. The greater the density and thickness of the part to be penetrated, the stronger the current must be, and within very much narrower limits, the higher the vacuum must be. Various tables have been prepared showing the relative density of different parts of the body and various other substances. It appears, however, to be a safe generalization to say that the resistance to the passage of the x-ray is greater for substances with greater specific gravity. This leads to some surprising results. With the fluoroscope we can see right through a black leather case, but the thin perfectly clear colorless glass vials look like so many cartridges. The chest in a good radiograph shows the nearly transparent lungs and the more opaque spine, ribs and heart, and lower down the great dense mass of the liver. Below that the abdominal contents are less opaque than the liver, but much more so than the lungs. The uppermost part of the thigh is a much more opaque object than the upper part of the chest.

The effect of ordinary light upon a photographic plate exposed directly to it, not in a camera, for a certain period of time is less the further the light is from the plate. This decrease in photochemic effect is considerably greater than would follow from the law that the illumination diminishes in proportion to the square of the distance. The distances in *x*-ray work do not vary so much, however, as to invalidate the law as to the square of the distance, but the thickness and density of parts of the body form a most important factor in the calculation. The practical application of the principles involved will be considered when describing the radiography of special parts of the body.

The Position of the Tube.—When an *x*-ray tube of the ordinary pattern is in operation, the tube is seen to be divided into a dark and an illuminated hemisphere by an oblique plane, which corresponds closely with the plane of the anticathode. Behind this plane there is very little *x*-ray to be seen with the fluoroscope. The statement is often made that the direction of greatest intensity of the *x*-ray is in a line drawn perpendicular to the center of the anticathode and, hence, coinciding with the middle of the illuminated hemisphere. Other authors state that the greatest intensity is in a line forming a natural angle of reflection between the cathode stream where it strikes the anticathode and the *x*-ray originating there. According to my own observations on tubes of several different patterns, the intensity of the *x*-ray is the same in every direction in the lighted hemisphere until the dividing line is almost reached. Theoretically, the *x*-ray should be equally diffused in every direction from the point of impact of the cathode stream upon the anticathode, and the dark hemisphere should be merely the shadow of the anticathode. In testing this matter the tube has been placed with its axis horizontal and has been operated by currents of different degrees of strength and observed by means of the fluoroscope and various test objects, like the hand and a pin-cushion. The author has found that for the same strength of current and the same distance from the tube, the intensity of the *x*-ray was the same in every direction corresponding to the illuminated half of the tube. And the same result was obtained when the tube was placed vertically.

It is much more convenient, in adjusting the tube and conducting cords so that there shall be no danger of the patient receiving a spark from the cords or the tips of the tube, to place the tube so as to use the rays which come at a right angle to the axis of the tube. So that, as a rule, the plate is upon the table, the portion to be radiographed resting upon the plate, and the *x*-ray tube with its axis horizontal and the anticathode directly above the center of the plate. And, as a rule, the two conducting cords, either of uncovered spiral steel spring wire, $\frac{1}{100}$ inch thick, or of thin flexible insulated copper wire wound on spring reels, extend directly from the poles of the coil to the two tips of the *x*-ray tube. The simplest arrangement is to place the tube so that the positive and the negative tips are equally distant from the poles of the coil, and the conducting cords do not rest upon any part of the tube stand. The special object is to have the wires extend in such a direction that they will not be anywhere near any part of the tube except the tips to which they are attached. In this way the possibility of puncturing the tube is prevented. And this arrangement renders it easy to avoid sparking from the wires to the metal parts of the tube-holder or to the regulator of the tube. Tube stands are provided with wooden rods to hold the conducting cords from undesirable contacts when this position is impracticable.

A large series of radiographs have been successfully made with tubes of different makes in this position. It is a curious fact, however, that the greatest amount of heat develops along a line drawn perpendicular to the surface of the anticathode, and under certain circumstances some tubes which are producing practically no *x*-ray will give an occasional distinct flicker in a direction decidedly beyond the angle of reflection of the cathode ray when it strikes the anticathode. This, I think, is due to the irregular cathode rays not being accurately focused on the anticathode. Some of them pass beyond the anticathode and strike the glass wall of the tube, giving origin to the *x*-ray there.

The Strength of Current in the Primary Coil.—This is the great factor in regulating the intensity of the *x*-ray from a tube. With some coils or transformers quite a beautiful *x*-ray may be produced with as low as 3 amperes; while other tubes and coils or transformers are made to stand a primary current of 30 or 40 amperes for a short time. Other things being equal, the heavier the primary current, the shorter the time required and the thicker the tissue through which a successful radiograph may be made. A current twice as strong will produce a picture in about one-tenth as long a time. Too heavy a current for the individual apparatus, of course, may burn out either the primary or the secondary coil; the excessive intensity causing the current to break through the insulation separating the different turns in the coils. A hundred dollars worth of wire may thus be ruined in a flash. The fuses down in the cellar and elsewhere along the feed-wires are to prevent such an accident and should be of such capacity as to permit the passage of only such a strength of current as may safely be used. Even then a too long-continued flow of a heavy current through the primary will heat up the thin wire in the secondary coil and may break down its insulation. A 12-inch coil should stand a primary current of 110 volts and 15 amperes for a minute at a time without trouble, and this should be long enough for the entire exposure for any picture, and a very much shorter time will ordinarily be sufficient. There are very few tubes made which will stand so heavy a current for a minute at a time. A Gundelach heavy anode tube, type G, with a bulb 26 inches in circumference and measuring 23 inches from tip to tip, has, in my hands, stood precisely such a test successfully. The majority of tubes will break down under such a strain. The tube may puncture or the anticathode may melt, or the vacuum may fall to such an extent that the production of effective *x*-ray ceases. Some other tubes may be used with as heavy a current as this by an intermittent exposure to prevent the tube from becoming overheated. A primary current of 10 amperes may be considered as the minimum for general radiography with a 12-inch coil, and any tube of 50-centimeter rating or over, with a heavy anode or a water-cooling device, ought to stand this long enough for a picture. Here again, however, if the time is more than forty seconds, most tubes will produce a better picture if the exposure is interrupted. Even one of the thin anode tubes may be used in this way with such a current; and the fact that they contain a much smaller amount of metal causes them to maintain the same degree of vacuum better than some of the heavier tubes; still, the heavy anode tubes are preferable for radiography. The weaker primary currents of 3 to 6 amperes work very nicely with an 8-inch coil and with tubes of 25- to 40-centimeter rating. As stated elsewhere, any conditions which produce a good fluoroscopic image of the part in question will produce a good picture, if the plate has the proper degree of sensitiveness and the exposure is properly timed with relation to the other factors.

Generally speaking, the intensity of the radiance is increased or diminished by using a stronger or a weaker current through the primary coil, and to a great extent the same instruments regulate both the amperage and the voltage of this current. The 110-volt direct current of the electric-light circuit passes through our liquid interrupters and iron wire rheostats, and enters the primary coil as a current of only 80 or 90 volts and with a volume of 15 to 18 amperes for routine work.

Reduction of Voltage.—There are several ways in which the voltage may be still further reduced and the same amperage maintained. The usual way is by means of a shunt circuit, the electric-light current wire dividing and part of the current passing through a suitable resistance, entirely separate and independent, the other part of the current passing through the *x*-ray apparatus. If we have an amperemeter at the wall socket measuring the total amount of current passing and another measuring the amount passing through the primary coil, the difference between the two will indicate the reduction in the voltage in the primary coil. Where a current divides in this way between two paths the volume, or amperage, passing through each is inversely proportional to the resistance, and the voltage in each is directly proportional to the amperage. Or a *voltmeter* may be placed upon the primary circuit, which will indicate directly the number of volts passing through the primary coil. A voltmeter may be made in the same way as a galvanometer, but so adjusted that the readings on the dial are in volts. There are two principal types of *amperemeters,* in one the hand is moved by the various lengthening of a wire which becomes hot during the passage of currents of different volumes; in the other the hand is moved by the effect of a current through a wire, or a coil of wire, surrounding a magnetic needle and tending to cause the needle to assume a position at right angles to the direction of the current. This is a comparatively simple matter and the reading is in amperes or milliamperes, as the case may be, regardless of the voltage of the current or the resistance in the circuit. The same types of instrument serve as voltmeters, but, of course, in the graduation of the instrument in volts it is necessary that the resistance in the circuit shall be a constant, not a variable, quantity. With a uniform resistance the amount of the current is directly proportional to the voltage; the amount of the current or amperage is what deflects the hand, but it also indicates the voltage or electromotive force which drives that amount of current through an unvarying resistance. The graduations upon amperemeters and voltmeters are always made by comparison with standard instruments. It would be difficult to construct one on entirely theoretic lines and have the graduations turn out exactly accurate.

Another apparatus for reducing the voltage of a current for *x*-ray purposes was published by Lallemont.[1] It consists of a jar of dilute acid through which the current passes between two lead electrodes. One of the electrodes is more or less conical with a cruciform cross-section, so that the deeper it is immersed in the liquid the greater the surface of contact, and, consequently, the greater the volume of current transmitted. Part of the current passes through the liquid, so that if 120-volt direct current is shunted through dilute sulphuric acid, 1° Beaumé, the voltage is reduced to about 60.

Very many of the operators in Europe use a current of 60 or 80 volts for *x*-ray work, obtaining it usually by means of a shunt-controller. In the United States, however, most of the *x*-ray coils are made to use the 110-volt or even the 220-volt currents, reduced only slightly in voltage by the ordinary resistance of the rheostat and interrupter.

The *regulation of volume of the primary current* for *x*-ray work varies from 3 or 4 up to 30 or 40 amperes, according to the nature of the picture to be made and the character of the tube and other apparatus employed. Two different forms of rheostat are in very common use for regulating the amount of current admitted to the apparatus from the electric-light circuit. The current in the latter, of course, is perfectly enormous, as is easily discovered by short circuiting it, for example, by touching the outlet and inlet wires with a pen-knife blade. There is a blinding flash of light and a piece of the knife blade is actually burnt right out. With any properly installed system of wiring there are fuses in the cellar and elsewhere which burn out when an excessive current like this is turned on by accident or by mistake, and the whole system becomes dead almost as soon as the flash occurs. Without such protection by fuses any electric-light current would be a source of the very greatest danger from fire, and even with it the very greatest attention should be paid to the proper insulation of the entire apparatus and wires. It is important to remember that the secondary current is of such high tension that it will break through practically any insulation, and that the wires leading from the coil to the tube must not be allowed to touch any other wires. If they do there will be a spark and an odor of burnt rubber, anything inflammable may catch fire, the fuses all burn out, and the current stops. The insulation of both wires is burnt through and then you have a couple of wires with permanently defective insulation. This last result is not so important in the case of the wires leading to the tube; they are not supposed to be fully insulated and, indeed, some of my favorite cords are fine bare iron springs. And in these cords the volume of current is very small, somewhere around 2 to 10 milliamperes, from which the danger of fire is nil. And again, these wires are only charged when in actual use and are then suspended in mid-air between the poles of the coil and the tips of the tube. The primary wires, however, carry a current of perfectly tremendous possibilities, are charged all the time except when the main switch is turned off, and are frequently in proximity to wood-work or drapery; and are very frequently indeed in contact with other wires. When we speak of the current in the primary wires as having such enormous

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[1] Archives D'Electricité Medicale, Bordeaux, France, Nov., 1904.

possibilities we may compare it to a water-main passing through a city street, tapped here and there by small pipes leading to faucets in the different houses. At these faucets the pressure corresponds to the difference between the level of the faucet and the level of the reservoir from which the water comes. The outlets are small and the amount of water which can escape is only the amount which that pressure can force through a hole of that size, but if we make a large break in the main, we will have an escape of water great enough to undermine the house if it is not promptly checked. The quantity of water and the pressure are always there, it is only that ordinarily the openings are so small as to present such friction or resistance that only a stream of the desired magnitude can escape. In the case of the electric-light circuit there is enough volume of electricity in the street main to run a number of large motors and thousands of electric lights. The amount of current which will pass through any apparatus is determined by its resistance which corresponds to the size of the opening at the water-tap or faucet. Diminish the resistance and as heavy a current may be obtained as is desired, do away with the resistance altogether by short-circuiting the current, and you have done almost the equivalent of making a break in the water-main and you get a perfectly tremendous discharge, but, fortunately, one which is almost instantly cut off by the burning out of the fuses all along the line from the apparatus to the main. Usually the apparatus itself will escape unharmed, but, of course, there is always the possibility of burning out the primary or secondary coil and changing a hundred dollars' worth of wire into twenty or thirty pounds of copper, and, of course, there should always be means at hand for extinguishing any slight conflagrations; or, it is better still not to have wood or drapery or carpets around. The only time that the present author ever had to extinguish a blaze was in connection with some absorbent cotton placed in the box containing a Caldwell liquid interrupter, to deaden the noise. This became ignited from the slight spark which it is hard to obviate at the contact between the lead electrodes and the copper conducting cords.

The heaviest current which will pass through a Caldwell interrupter is from 9 to 11 amperes; this is without any rheostat and simply the resistance presented by the coil itself and for a very great many radiographs this strength of current will be found to be ample.

Rate and Character of Interruptions.—In the *Caldwell* or *Simon interrupter*, for they made the invention independently and at about the same time, the priority I think belonging to Caldwell, the supply current passes through dilute sulphuric acid, about one to six. One lead electrode dips into acid in an inner beaker of tough porcelain through which pin-holes establish communication with dilute acid in the outer jar in which dips the other lead electrode. It does not matter which is positive and which is negative. When a heavy current is passed through such an apparatus the resistance is very great at the pin-holes, where the size of the conductor is very small. The liquid conductor actually boils at these points and bubbles of vapor fill the pin-holes and for a moment the connection is broken. The current begins to flow again the moment the bubble collapses or escapes, and in some interrupters of this type the current is made and broken ten thousand times a minute. The dilute acid is an electrolyte or fluid in which electrolysis takes place and, consequently, bubbles of hydrogen gas are liberated at the negative and of oxygen at the positive electrode. This does not seem to be of importance in the production of the interruptions, its practical bearing being the fact that a mixture of free oxygen and hydrogen is explosive if ignited by a spark. Such an interrupter should always be provided with free ventilation. The operation of a Caldwell interrupter is accompanied by the production of irritating sulphurous acid fumes and by heating of the liquid. When the liquid gets too hot the interrupter will no longer act and it is desirable to have several interrupters and simple switches to connect different ones with the coil. If these have pin-holes of different sizes we have the added advantage of being able to select the size best adapted to the case in hand. The smaller the pin-holes the more rapid are the interruptions and the less powerful is each impulse sent through the tube by the secondary coil. This is a desideratum for treatment and for the lighter forms of radiography, while for the heavier radiographic work such an interrupter should have large pin-holes. With the small pin-holes the primary current when turned on full is only 3 or 4 amperes, while with large holes it may be as heavy as 11 amperes. There are, of course, modifications of this simple type, and in one of them the size of the communication between the two portions of fluid can be regulated by the motion of a conic plug, which more or less completely fills the hole. Up to the limit of its capacity the Caldwell interrupter is one of the most satisfactory in the production of a brilliant steady x-radiance.

The *Wehnelt interrupter* consists of a single jar of dilute sulphuric acid. The negative electrode is of lead; the positive electrode or anode being a platinum rod enclosed in a closely fitting, very tough, porcelain tube and the distance that it projects beyond the end of the tube can be regulated. The greater the surface of the platinum point exposed to the fluid, the more powerful is the current and in a general way the slower are the interruptions. When in active operation the platinum point is seen enveloped in a regular flame and the fluid about it is cloudy and fiercely agitated. The probable cause of the interruptions is the production of a layer of steam covering the whole surface of the platinum point. There is, however, vigorous electrolysis going on with the generation of hydrogen chiefly at the negative pole and of oxygen chiefly at the platinum point forming the anode. And owing to self-inductance and an inverse current in the primary circuit, there is also, to a lesser extent, a liberation of hydrogen at the anode. The bubbles of gas do not form a sufficiently uniform covering on the anode to account for the interruptions, though they doubtless exert an influence upon the nature of the interruptions produced. With this interrupter the fluid becomes hot and the apparatus fails to work after continuous use, so that it is necessary either to have one containing a very large amount of liquid or to have more than one interrupter. The Wehnelt interrupter is often made with more than one anode and if so the platinum tips may be of different sizes. There is the same necessity for ventilation in order to avoid explosion. The Wehnelt interrupter must not be run with the poles reversed. If the negative wire is connected with the platinum point and the positive wire with the lead electrode the interruptions, if produced at all, are of a deeper and rougher sound and the current very quickly corrodes the platinum point. For this reason the Wehnelt interrupter is not suitable for use with an alternating current, or, if it is so used, the expensive platinum point should be replaced by one of copper wire which can be renewed as fast as it is consumed.

The Caldwell interrupter may be used with an alternating current by introducing an *aluminum cell* into the supply circuit. This is a cell filled with a 6 per cent. solution of Rochelle salt; the two electrodes being of aluminum and lead respectively. This acts by suppressing the impulses in one direction and, of course, is much less efficient than a commutator or any form of dynamo in which the alternating current generates a continuous direct current. Still, a Caldwell interrupter and an aluminum cell form a simple and inexpensive combination and produce a very good *x*-radiance for treatment or for the lighter demands of radiography.

Mechanic interrupters are made on two different principles. In the older type the contact is made and broken by the vibration of an armature in front of an electromagnet. The primary current, or a shunted portion of the primary current, passes through a coil of wire surrounding a core of soft iron which becomes a powerful magnet the moment the current begins to flow. This pulls the armature, which is on a spring, toward it, and thus the connection is broken and, of course, the iron ceases to be a magnet and allows the armature to spring back to its original position, where the contact is again made. One of the supply wires leading from the wall socket to the apparatus is cut in two and one end is connected with the armature and the other is connected with the metal against which the armature is pressed by the spring. The rate of vibration depends partly upon the weight of the armature and partly upon the distance it has to travel, and this is usually adjustable by means of a screw. Such an interrupter of an improved design is shown in Fig. 523. The interruptions produced are much slower than is the case with a liquid interrupter and it is not suitable for the heaviest currents, so that its utility in radiography is somewhat limited. It is especially useful for treatment work because it can be run all day long.

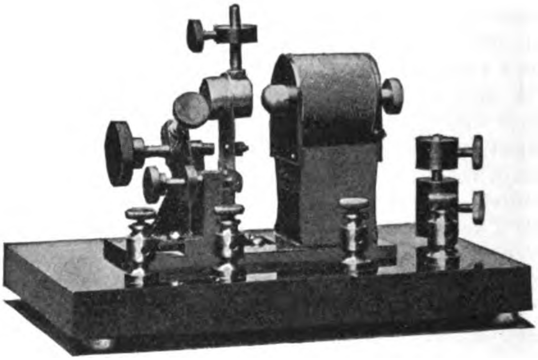

Fig. 523.—Improved Queen independent vibrating interrupter.

The Wappler Mechanic Interrupter.—Another mechanic interrupter has recently been developed, by different manufacturers in America and Europe, along slightly different lines. Essentially it depends upon the revolution of a wheel in which two opposite spokes are formed by a single permanent magnet. This is placed near the end of the iron core of the induction-coil. The latter, of course, is a powerful electromagnet with a certain polarity during the flow of the current, and ceases to be a magnet after the current stops. The positive pole of the revolving magnet when in a certain position is attracted by the iron core of the coil, and this attraction causes the wheel to revolve into such a position as to bring this pole of the magnet as near as possible to the iron core. By the time it has reached this position the break in the circuit has occurred, the iron core is no longer an electromagnet, and the momentum of the wheel carries it around to such a position that the newly and oppositely magnetized iron core attracts the other pole of the revolving magnet. The motion is a continuous one, resembling that of a windwheel or a water-mill. The rapidity of revolution may be varied by changing the distance between the revolving and stationary magnets. The contact occurs between two flat metal surfaces, ¾ inch in diameter, and there is considerable sparking. The interrupter is contained in a box lined with sheet-iron to prevent the sparks from setting fire to the box or neighboring objects. If too strong a current is turned on, or if the interrupter is not working properly, the contact surfaces may become welded together. This is not a serious accident, however, for usually only a small part of the two surfaces adhere to each other and they are easily separated and smoothed again. A condenser weighing five or ten pounds is required with this interrupter and a rheostat with a minimum of 8 and a maximum of 16 ohms resistance. This will interrupt a current of as little as ½ ampere and as much as 5 or 10 or with special condensers even 20 amperes. It is especially useful for high-frequency currents and for x-ray treatment tubes for contact application where the strength of current must be very small. It is made especially for the 110-volt direct current, but can be used with an alternating current and an electrolytic rectifier. It causes a Müller No. 13 x-ray tube to produce a suitable radiance for therapeutic use. It is available also for radiography and gives better contrast, but takes a little longer than the liquid interrupters with very much heavier currents. A 5-ampere current with this interrupter will produce a radiograph of the frontal sinus in a minute which is about as good as that produced by 18 amperes with a Wehnelt interrupter in thirty seconds.

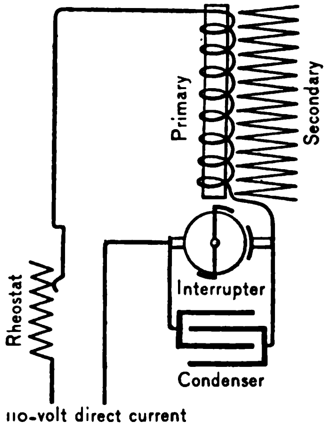

Fig. 524.—Connections for wheel interrupters.

Wheel Interrupters with Mercury Jet and Illuminating Gas Arc Suppression.—Drault and some of the other European manufacturers make a wheel interrupter on the same principle as the Wappler interrupter, except that the motion of the revolving magnet actuates a mercury jet interrupter (Fig. 525). The interruptions take place in a closed iron cylinder filled with illuminating gas which is non-combustible in the absence of air. This prevents the oxidation of the mercury and iron which takes place when alcohol is used to suppress arcing. The apparatus, therefore, requires less cleaning. The same claims are made for it as for the Wappler wheel interrupter, but, of course, the mercury turbine makes it a little more complicated. A dangerous explosion would occur if it were started when full of a mixture of air and illuminating gas.

Mercury Turbine and Mercury Dip Interrupters.—The other great type of mechanic interrupter is one in which the contact is made or broken, either by the throwing of a revolving jet of mercury against metal connections, or the dipping of a metal connection into mercury. In either case the power is usually supplied by an electric motor. The mercury turbine can be made for a very wide range of speed and can be run for a long time. In both the mercury interrupters there is a layer of alcohol or oil to suppress the spark, which would otherwise be excessive and which would cause the making and breaking of the contact to be less perfect than they should be.

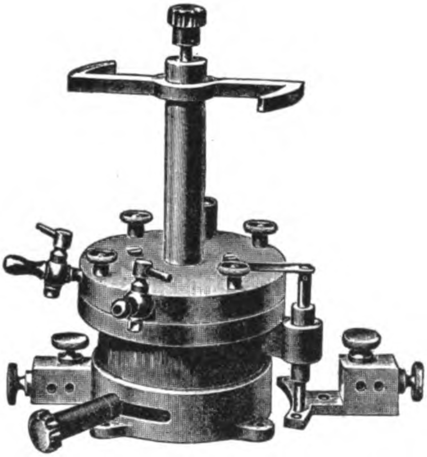

Fig. 525.—Wheel interrupter with mercury jet and illuminating gas.

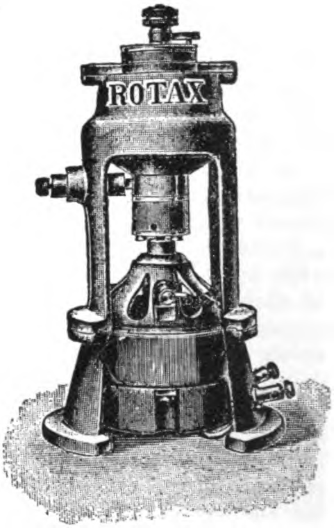

Fig. 526.—The Rotax interrupter.

The Rotax Interrupter (Fig. 526).—This is made by the Sanitas Company of Berlin, and is a mercury interrupter in which the arcing is suppressed by petroleum oil. The metallic vessel containing the mercury revolves at a high rate of speed. The mercury is held against the side of the vessel by centrifugal force and there are two insulated segments which break the contact between a metal rod connecting with the other pole and the revolving mercury. The claim is made for it that it will work with any voltage, or that it can be used with a storage-battery or with the direct electric-light current. It is also said to give much less inverse discharge than the Wehnelt or the mercury jet interrupter. The radiographic and fluoroscopic results should be correspondingly better.

The Villard Interrupter for Alternating and Triple-phase Currents.—A vibrating strip of soft iron is placed between the arms of a permanent horse-shoe magnet and carries at its distal extremity a strip of nickel, which dips into metallic mercury when the vibrating iron is attracted by the lower pole of the magnet, and is raised out of the mercury when the soft iron is attracted by the other pole. It is at the surface of the mercury that the current for the x-ray coil is made and broken. A weaker current, derived by a shunt from the alternating or the triphase circuit, passes through a coil which surrounds the soft iron, and makes it an electromagnet with a periodic reversal of polarity. When it has a certain polarity it is attracted by one pole of the horse-shoe magnet, and when it has the opposite polarity it is attracted by the other pole of the horse-shoe magnet. Its periodicity is the same as that of the alternating or triphase current which it is to interrupt, and it is only a matter of proper adjustment to make a contact with the mercury during the flow of currents in one direction and to break it during the flow in the opposite direction.

To use it with triple-phase currents one connects the interrupter with only two of the wires supplying the current. An interrupter upon this principle is shown in Fig. 527.

Ordinary vibrating interrupters of the type familiar in the faradic coil are not suitable where heavy currents are to be employed. A condenser is always required when such an interrupter is used.

Among the earlier types of apparatus was the Edison make and break wheel making 8000 to 20,000 revolutions a minute when run by a separate motor. It required a blower to extinguish arcs and made a great deal of noise. The switch was so arranged as to start the interrupter before the primary current was turned on. The Willyoung interrupter was similar, but the contact points were immersed in oil, which reduced the arcing and noise.

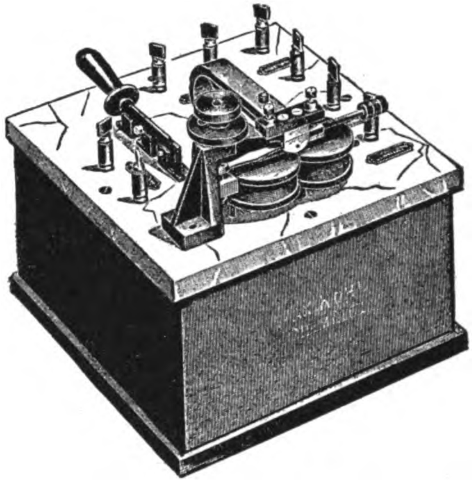
Fig. 527.—Electromagnetic interrupter for alternating or triple-phase currents.

The *Johnston interrupter*, made by the Westinghouse Company, is a mechanic interrupter in which an electric motor rotates an inclined shaft whose lower end is immersed in oil or alcohol, covering the contact points.

With the Caldwell or Simon and with the Wehnelt interrupter no condenser is required, but for any form of mechanic interrupter a *condenser* is necessary. This consists of a number of sheets of tin-foil in two series of layers, one series connected with one wire and the other series dovetailing between and connected with the other wire. All these different pieces of tin-foil are insulated from each other by sheets of paraffin paper or mica. When a current of electricity passing through a primary coil is suddenly interrupted, a certain amount of charge, or difference in potential, is found to be present in the primary coil, and this, of course, produces a current in the primary coil which will have an effect, in turn, upon the spark discharge of the secondary coil. The large surface of the condenser forms a sort of reservoir for this charge, or difference in potential, and as a matter of fact its presence does actually make the difference between a successful induction-coil and one which will not work well. Its function is roughly to be compared to that of a fly-wheel in machinery. The necessity for a condenser in any coil with a mechanic interrupter adds greatly to the weight of the apparatus and makes it somewhat less available for a portable outfit.

The Self-inductance in the Primary Coil.—The primary coil is of comparatively thick wire, wound upon a long spool, and may be in a single layer or in several layers. If the latter, the self-inductance may be variable by means of plugs or screws, so that the current may pass through only one layer or through two or more. In the latter case the connections may be such that the different layers in use form one continuous circuit like the thread on a spool, or they may form two or more parallel circuits. There is an induced current produced in any wire near another in which a current of electricity passes, and this is produced even if the two wires in question are but parts of the same wire coiled in several turns. Lewis Jones,[1] of London, has published very valuable tracings showing the difference between the waves of electricity produced in the secondary coil by varying the self-induction in the primary. He finds that for therapeutic purposes (faradic coils very much smaller than the induction-coils for *x*-ray work) the secondary current, produced with a small self-induction in the primary, is more effective in producing muscular contraction and less painful than with large self-induction. The difference in the tracings shows that with small self-inductance the make and break currents reach their maximum at one bound and come down to the level by a short steep curve; whereas the return to the zero line in the secondary current when there is large self-induction is by a long inclined line. In the case of *x*-ray coils the practical value of variable self-induction consists in the fact that a tube with a high vacuum generally works better with great self-induction and vice versâ. This is because the tube with the higher vacuum requires a more powerful secondary discharge, and this is just what is produced by a primary coil with large self-induction. Disconnecting the *x*-ray tube and observing merely the spark passing between the poles of the coil, the spark is about twice as long and twice as heavy with high self-induction as with little self-induction. The author has made such an experiment with a 12-inch coil, a Caldwell interrupter with small holes, and the rheostat resistance all out, so that there is no external resistance to the 110-volt direct current. With the long primary winding and consequent high self-inductance a heavy spark passed across a space of 7 inches, and with the small self-inductance a lighter spark passed across a space of only 3½ inches. In the case of the greater self-induction and the longer and heavier spark the amperemeter showed that only 3 amperes were flowing through the primary coil, while in the other case almost 5 amperes were flowing. The longer primary coil of wire, of course, presents more resistance (analogous to friction), and then, again, the induction of a heavier secondary discharge represents an increased amount of work done, so that there are two ways in which the quantity of electricity passing through the primary coil is varied by conditions in the coil itself. The same thing which is true of the spark between the disconnected poles of the coil is also true, in a general way, of the effect produced upon an *x*-ray tube. But here there are several other

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[1] Brit. Med. Journal, Oct. 8, 1904; Trans. Archives d'Elec. Med., Nov. 10, 1904.

elements, so that sometimes a tube will give a better radiance and be more free from inverse discharge with great self-inductance, and another tube will work better with low self-induction; and this is something which cannot always be determined theoretically, but must usually be found out by actual trial. It is a good working rule that no tube will give very much of a picture of any part of the body unless it shows quite a beautiful image of the same part in the fluoroscope. Given this favorable radiance, the actual taking of the picture is largely a matter of using the proper strength of current and duration of exposure required for the part of the body to be radiographed.

The Amount of Current Passing Through the Tube.—The volume of the secondary current, as shown by the fatness of the spark between the poles, is greater when more of the platinum point is exposed in the Wehnelt interrupter, the primary current is stronger as to amperage, and the interruptions are less rapid. The heavier secondary discharge throws a heavier charge through the *x*-ray tube and causes the anticathode to heat up more quickly. Too heavy a charge will make the platinum white-hot at the focus point and in another instant fuse the platinum. There is warning enough of this, however, by the white heat of the platinum and by the streak starting from the focus point and extending at a right angle to the bluish cathode stream, which also becomes visible. When such an accident occurs it is the end of the tube as far as that exposure goes, but later, after it has cooled, it may be found still quite serviceable, and the author has taken many a pelvic picture with a heavy anticathode in just this damaged condition. For lighter work where greater detail is possible, of course, a tube with an unbroken surface at the focus point would be preferable. The charge which one tube will stand for thirty seconds might easily burn a hole as large as the lead of a pencil completely through the disk in another tube. Generally speaking, the larger the tube and the heavier the anticathode the heavier current it is intended to stand. The charge is sometimes increased by increasing the self-inductance in the primary coil, by increasing the length of the platinum point exposed in the Wehnelt interrupter, and by reducing the resistance in the rheostat. The relation between regulation of the primary current by varying the rheostat and by varying the Wehnelt interrupter are important. In my own experiments a primary current of 10 amperes, as produced by the use of the Wehnelt without any rheostat, produces an incomparably better *x*-radiance than by exposing a greater length of platinum in the interrupter and reducing the current to 10 amperes by increasing the resistance in the rheostat. In fact, a 6-ampere current produced by regulating the Wehnelt alone gives very much better results than a 12-ampere current produced by the other method. With the rheostat resistance and a large surface of platinum exposed the interruptions are halting and irregular, the secondary discharge weak and intermittent, and the *x*-radiance weak and flickering.

The quantity of electricity passing through the tube is a very great deal smaller than the quantity passing through the primary coil. The latter for a great many cases is about 10 amperes, while the former is often between 2 and 3 milliamperes. The potential or voltage of the discharge from the secondary coil is somewhere in the region of a thousand times that of the 110-volt primary circuit, but the quantity of electricity in the secondary is only about $\frac{1}{8000}$ part as much as that in the primary current. For a long time it was found impracticable to measure the quantity passing through the tube, the tension of the current being so great as to render it very difficult to insulate the wires in their passage through any instrument. In the summer of 1904, and practically simultaneously, Gaiffe of France, Snooks of Philadelphia, and Weston of New Jersey succeeded in making practicable instruments for this purpose. Gaiffe's is a hot wire galvanometer, and Snooks' and Weston's are electromagnetic galvanometers. The secret of success seems to have been the discarding of the idea that tremendous insulation is necessary. The difference in potential at different parts of the same wire leading from the coil to the *x*-ray tube is comparatively small. The hot wire milliamperemeter registers the same, no matter how much the inverse discharge may be interfering with the operation of the tube, while the electromagnetic meter shows this effect at once. These meters are usually marked from 0 to 10 milliamperes for use with a coil, and from 0 to 2 milliamperes when a static machine is used. This represents about the usual difference in power between the *x*-radiance produced by the coil and the static machine. The current passing through the tube measures, of course, not only the power generated by the coil but also the resistance in the tube, and this varies with its degree of vacuum, so that the instrument is of service in estimating the power of different coils and also for showing the condition of the tube at every instant of the exposure in making a radiograph. To a certain extent it indicates the effectiveness of the ray produced, and in this way serves as a guide to the length of time required for the exposure. The same, of course, holds true in regard to the therapeutic use of the *x*-ray. All this, however, is valueless and even misleading unless combined with the many other factors already alluded to for obtaining or recognizing the proper quality of radiance. It is especially important not to rely upon this milliamperemeter on the secondary circuit to the exclusion or neglect of the amperemeter on the primary circuit. The latter indicates the amount of current admitted to the apparatus; it shows whether there is danger of burning out the primary or secondary coil or the rheostat or any of the fuses. If one is doing heavy work at all it is absolutely essential to the safety of the apparatus to have an amperemeter on the primary circuit, and with it one can very well accomplish every desirable effect without the milliamperemeter on the secondary circuit, this being in radiography only a valuable accessory.

The milliamperemeter gives exact results when a Villard soupape (ventril or valve tube) is used in series with the *x*-ray tube to prevent the inverse discharge; but the results are rather vague unless the spark equivalent is at least 3 or 4 centimeters.[1]

It happens now and then that the meter indicates a current in the wrong direction and this means that the inverse discharge not only is not suppressed, but that it is in excess of the direct discharge. This condition may not prevent the production of a good radiograph, or of a good therapeutic or fluoroscopic effect, providing there is also a good direct discharge, which is sometimes the case. As a rule, however, when there is considerable inverse discharge the direct discharge is deficient; and considerable inverse discharge always produces excessive wear and tear upon the tube.

[1] Lewis Jones, Le Radium, September 15, 1905, p. 300.

The Point and Plate Parallel Spark-gap.—This may be used as a sort of valve to suppress the inverse discharge. It is placed between the poles of the coil and so near together that the discharge in one direction (*i. e.*, when the plate forms the cathode and there is an inverse discharge) will pass across the spark-gap. If the distance is properly adjusted the discharge in the opposite direction cannot cross the air-gap, but will be driven through the tube. The point should be connected with the cathode and the plate with the anode of the tube (Fig. 528).

Measurement of the Difference in Potential at the Poles of an x-Ray Tube.—A static voltmeter may measure the difference in potential between the two poles of an x-ray tube and consequently the resistance of the tube. The voltage is so great that Gaiffe[1] has adopted the expedient of connecting the poles of the tubes to a series of condensers. The armatures of one of the condensers are connected with the static voltmeter. The fraction of the voltage thus measured is one divided by the number of condensers. The graduations on the voltmeter may be in volts or directly in degrees of the Benoist radiochromometer, but the graduation must be done for the particular apparatus that the voltmeter is to be used with.

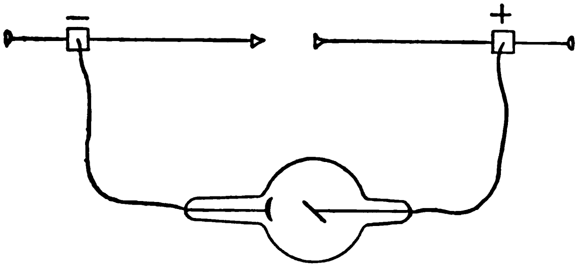

Fig. 528.—Point and plate spark-gap to prevent inverse discharge.

Backing for the Plate in Radiography.—There are many conditions in which it is desirable that more or less of the patient's weight shall rest upon the plate. This makes my backing for x-ray plates very desirable. It consists of a board, measuring 14 by 17 inches and ⅜ inch thick, covered on its lower surface by smooth cardboard and on its upper surface by x-ray metal and bound around the edges with adhesive plaster. It is thin enough to be placed upon the table under any part of the patient without discomfort, and strong enough to prevent the plate from breaking under the weight of the heaviest patient. Its under surface is smooth enough not to scratch the polished wood top of a table, and its strength is such that it may be used on top of cushions or in bed, where otherwise the patient's weight would assuredly break the photographic plate. The x-ray metal surface prevents diffused rays from reaching the plate from behind.

Radiographs Made With a Single Flash.—This is only practicable with a mechanic interrupter. A single example will show the principle upon which this depends. If the interrupter is of the vibrating type it is screwed so far back that it cannot make contacts by simple vibration, then it is pressed into contact and the primary current is turned on. The vibrator is suddenly released by the hand which has been

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[1] Exposition de Physique, April, 1907.

holding it and a single permanent break occurs in the primary current and a single induction discharge passes through the x-ray tube. The current should be stronger than is ordinarily employed and if the x-ray tube is absolutely in readiness, especially as to the degree of vacuum, a really instantaneous x-ray picture may be obtained. The amount of impression upon the plate in such a short time will, of course, be very slight and only some thin portion like the hand can be well depicted.

By using the negative cinematograph film between two intensifying screens the heart may be radiographed in motion. A number of such pictures, taken at different parts of the cardiac cycle, could be used in the cinematograph to show the heart in motion.

Fluorophotography.—This process, which consists in making a photograph of the image on a fluorescent screen, was first published by Dr. J. M. Bleyer.[1] It does not seem to present any advantage over ordinary radiography directly upon the plate or film, unless one desires a reduced sized picture.

Radiographic Determination of Death.—Voileant[2] says that a radiograph of a dead person shows the stomach and all intestinal convolutions very clearly; in the living person the constant peristaltic and respiratory movements obscure the outlines of the different structure. This is especially true with rather long exposures, such as a minute or several minutes.

The Radiograph a Professional Secret.—The Paris Academy of Medicine has resolved: "A radiograph is a document consisting of something taken directly from the patient, is something of the personality of the patient, and, therefore, the use of a radiograph comes under the law of professional secrecy in its strictest sense. Take, for example, a case of early phthisis, or a man with syphilitic exostoses, examined by a man outside of the medical profession who is not bound to professional secrecy."

LOCALIZATION OF FOREIGN BODIES

Bullets and other foreign bodies embedded in the flesh may be readily seen with the fluoroscope and in the radiograph, and still it may be somewhat difficult to say at just what depth they are located in the tissues. This information may be directly gained in any portion of one of the limbs by making two successive radiographs at a right angle to each other. It will greatly facilitate the surgical removal if a metal marker like a small shot or a very short piece of heavy wire be fastened with adhesive plaster to mark the wound of entrance. This should be in contact with the plate and, therefore, at the center of the first radiograph and should be at the extreme edge of the image of the limb in the second.

In Figs. 529 and 530, referred for examination by Dr. Wadhams, the lateral radiograph showed a needle broken off in the heel $\frac{1}{4}$ inch in from the wound of entrance and extending upward and backward for 1 inch. The anteroposterior radiograph showed that the needle did not incline outward or inward, but lay in a median plane. It was easy enough for the doctor to find and remove it.

W. M. Brickner, of New York, was among the first to suggest fastening

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[1] Trans. Royal Acad. Med. and Surg., Naples, April, 7, 1896.
[2] Semaine Med., Nov. 27, 1907.

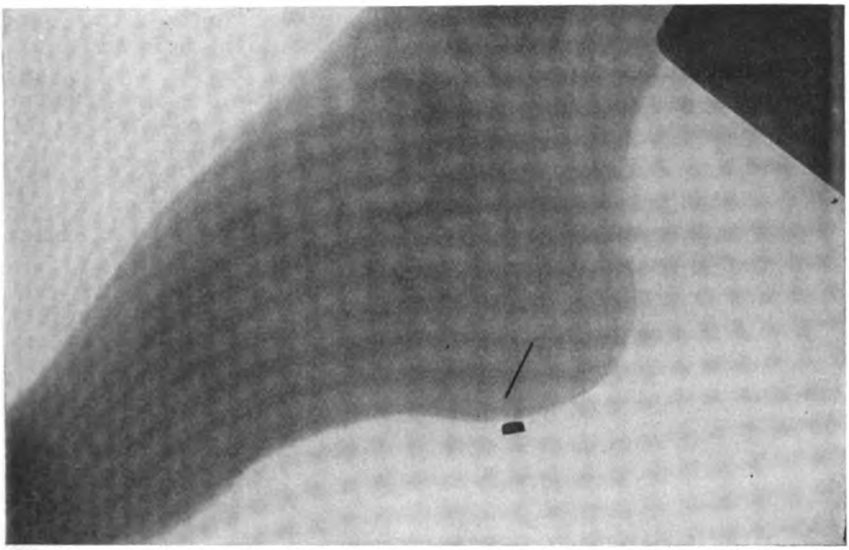

Fig. 529.—Localization of needle in heel. Lateral view showing needle and metal marker at wound of entrance.

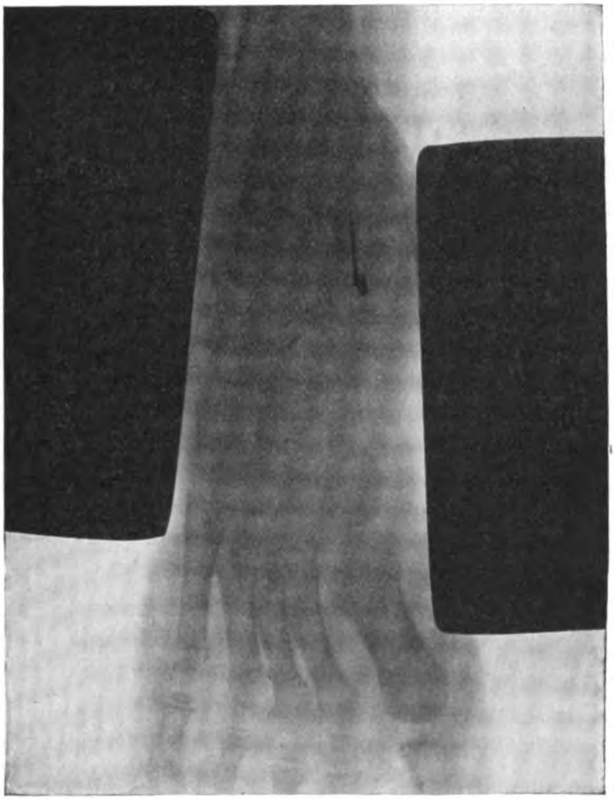

Fig. 530.—Localization of needle in heel. Anteroposterior radiograph. Bit of lead as external landmark.

a metal marker to the skin either toward or away from the plate in conjunction with a modification of the Mackenzie-Davidson localizer.

Foreign substances in any part of the trunk may be localized by making two successive radiographs upon two separate plates with the body in the same position with reference to the plates and with the tube shifted a certain distance to one side for the second picture. A calculation based upon the distance from the *x*-ray tube to the plate, the distance to which the tube is displaced laterally and the resulting displacement of the image of the foreign body, will give the distance of the latter from the plate.

The Mackenzie-Davidson Localizer.—This is the prototype of a class of apparatus designed to give this information in a mechanic way, *i. e.*, without mathematic calculation. The photographic plate for each picture is placed under cross-wires, whose position may be marked upon the body and whose position is radiographed upon the plate. The anticathode of the tube is placed at two definite places for the two successive pictures (Fig. 532). After the plates have been developed one is placed in the localizer so that the cross-wires of the latter coincide with the image of the cross-wires on the plate. A thread is fastened at the image of the foreign body and at a pointer which is held just where the anticathode was placed for this picture. A thread is drawn in a similar way from the image of the foreign body on the plate to the position then occupied by the anticathode. The place where these two threads cross is the place occupied by the foreign body relatively to the photographic plates (Fig. 531).

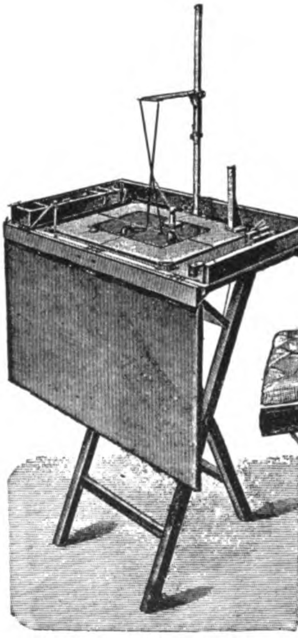

Fig. 531.—Mackenzie-Davidson apparatus for localization of foreign bodies.

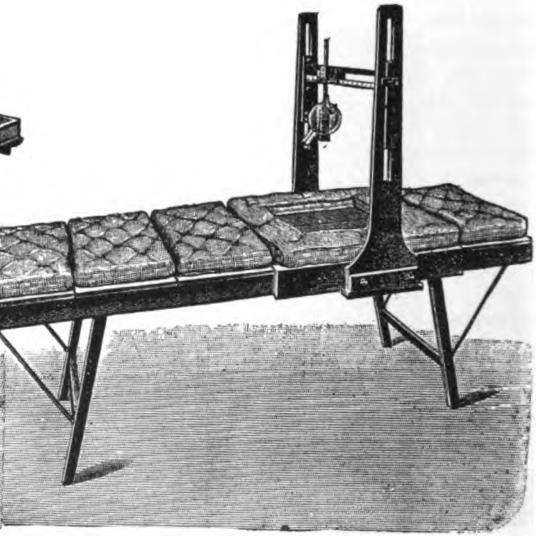

Fig. 532.—Mackenzie-Davidson apparatus for localization of foreign bodies.

DEVELOPMENT OF X-RAY PICTURES

The **dark room** ought to be entirely free from ordinary light, either daylight or artificial light, except as allowed to enter through ruby and orange glass or their equivalent. If it is a room with windows no number of dark shades and ordinary blinds with slats are going to exclude the light sufficiently. Either all the panes of glass must be treated as described later or else solid board shutters must be provided which will close so accurately as not to admit a solitary ray of light. In order to use the daylight it will be necessary to have all the panes which are not securely boarded up consist of one thickness of ruby and one thickness of orange glass, or else the glass may be ordinary colorless ground glass pasted over with two thicknesses of the red paraffin-coated paper used in the original packing of sensitized plates, and one thickness of the orange paper known as "post-office paper." Such a window should be shielded from the direct rays of the sun and if the window is very large, or if there is more than one window, it is better to absolutely darken all but about 2 square feet of one window, and treat just that area so as to admit only safe light.

Excellent outfits are made by the Polyphos Elektrizitats-Gesellschaft, of Munich, of the nature of shades for ready application to the windows of a room in order to convert it into a dark room.

The dressing-room, as found between the front and back rooms of many city houses, forms an excellent dark room. The doors usually have ground glass panels and these may be prepared with red and orange paper, and a good strong artificial light of any kind, placed close to the outer surface of one of the panels, will send just the right amount of safe light into the dark room to enable one to work easily and to see the plate clearly enough to regulate the degree of development.

In the same way if the dark room is a specially constructed box-like affair, a small window of ruby and orange glass may be cut at a convenient height and the light placed outside.

The *Cooper Hewitt light* of 400-candle-power is excellent for this purpose, but an ordinary incandescent electric light may be used, or a *Welsbach* gas burner, or a powerful oil lamp. In the case of any but the Cooper Hewitt it is desirable to have a pair of planoconvex lenses, 6 or 8 inches in diameter, acting as a condenser; otherwise the light may be found too weak and diffused for proper study of the plate.

In every case the light should be admitted at some distance from where the developing trays are placed and should be strong enough to just enable one to see everything in the dark room and to read the labels on bottles if the latter are brought close to the ruby window. Too brilliant a light, even if considered safe as to color, will act upon the plate and produce either flatness or fog.

For a room or closet without windows or glass doors *artificial light* inside the room is a necessity. A 16-candle-power ordinary incandescent electric light with a ground glass bulb and enveloped in two thicknesses of ruby and one of post-office paper makes a safe light if placed at a distance.

A lamp is made expressly for this purpose by the New York Incandescent Lamp Company. It is known as a *tipless, frosted, natural ruby incandescent electric bulb* and either a 16- or a 32-candle-power lamp may be used. This is complete in itself, or an ordinary ruby bulb may be placed in a box with a ruby and orange glass window measuring about 4

ALBERS SCHOENBERG'S TABLE OF X-RAY EXPOSURES

Qualities suitable for radiography.	Scale.		Spark length of a new tube.	Grade of self-induction of a 60-cm. coil with Walter's apparatus.	Length of platinum point of Wehnelt 1 mm. thick.	Indication.			
	Walter.	Benoist.							
Medium soft.	7	6	25 cm.	3 (510 windings of primary)	10 mm.	Hip-joint, Pelvis, Spinal column, Renal calculi.	Always with diaphragm.	In corpulent patients. Moritz's measurement.	Orthodiagraphic. Large patients never without diaphragm.
Soft.	6	5	12 to 15	4 (680 turns)	9 to 10 mm.	Pelvis, Hip-joint, Spinal column, Kidney stone.	In average patients with diaphragm.	Skull, Neck, Upper extremity, Shoulder, back teeth.	Orthodiagraphy of thin persons and children. General picture of chest without diaphragm.
Very soft.	5	4	11 to 16	5 (850 turns) 6 (1020 turns)	5 mm.	Teeth, Hands, Thorax.	Children's extremities. Hip dislocation in sucklings. Picture of young children.		

Characteristics of *x*-rays.			Of course, with rays No. 8 a pelvis can be taken in fifteen seconds and a hand instantaneously, but the picture lacks perspective. It is simply a shadowgraph.
Hard.	8		Wires show discharge and sparks around the tube. Fluorescent flecks especially around anode (inverse discharge). Relatively little fluorescence of the tube. Bones of hand appear clear, gray, transparent. Carpal bones clearly distinguishable. In radius and ulna recognize cortex and marrow canal. Not of any use for radiography.
Medium soft.	7		No or very little brush discharge from wires. Clearly divided, no flecks. Bones appear grayish black. Carpal bones clearly distinguishable. Metacarpals and phalanges show a marrow cavity and cortex.
Soft.	6	5	Phalanges and metacarpals black. Soft parts of fingers dark and contrasting well with background, which appears especially bright in consequence. The carpal bones cannot be distinguished from one another. The radius and ulna can well.
Very soft.	5 4	4 3	Hand bones inky black. The fluorescence of the tube has a bluish tint. There is often anode light.

by 5 inches. Others consist of an ordinary ruby bulb completely enclosed in a heavy shade of natural ruby glass. Excellent dark-room lanterns are made with a candle in an automatic candlestick, which keeps the flame at a constant level until it is completely burned out. There is a ruby glass chimney closed in such a way at the top and bottom that while there is a circulation of air through it no rays of ordinary light can escape. This will answer every purpose in developing the smallest films and plates, but will not give enough light for the larger ones.

Other *ruby lamps* are made in various sizes with an oil lamp enclosed in tin with a window of two sheets of glass, one ruby and one orange.

The amount of time for which the plate may be safely exposed to these various ruby lights is to be most carefully considered. Generally speaking, the process of taking the plate or film from its original container and placing it in the black and orange envelopes, in which the exposure to the *x*-ray is made, and again removing it and placing it in the developing solutions, should be done without any unnecessary delay. The plate is most liable to damage before it has been put into the developing solutions. During development the ruby light should not be allowed to shine directly upon the plate, except for a moment from time to time to permit of examination. If the plate is one which is of such a character as to require only a few minutes' development, simply shielding it from the direct rays of the ruby light will suffice; but if it requires from twenty minutes to two hours or more for development, the tray or tank in which it is developed should be closely covered during all this time, except occasionally for examination. These inspections of the plate should be as infrequent and as brief as possible.

Staining Solutions.—Quite another way of protecting the plate from actinic light during the process of development is by the use of an agent which stains the plate and the developing solutions red, and enables the whole process to be carried out by ordinary light. One such agent is a liquid sold under the name of *coxin* and looks like a strong solution of cochineal. The plate must be immersed in this solution for two minutes and then taken directly from it to the developer without allowing any of the staining fluid to drain off. While the developer is acting the plate must not be taken out of the fluid and the development must be watched by direct, not transmitted, light. When sufficiently developed the plate is washed off in water and placed at once in the acid hypo. After fixing completely, place the plate in running water for half an hour to wash out the hypo and the red stain of the coxin. The entire process after once getting the plate into the coxin may be carried out by daylight or artificial light, but, as in the other cases, it is better to shield the plate from a strong light except when necessary to see how the development is progressing. Dark colored developing trays must be used. In putting the plate into the coxin no white light must touch the plate, so it is either necessary to go into a dark room or to have a black transferring bag, by means of which the plate may be taken from its envelope and placed in the coxin without exposure to light. The utility of this method is apparent when taking and developing *x*-ray pictures at patients' houses or under any other circumstances where a regularly equipped "dark room" is not available. This method is equally available for plates and films.

Technic of Development.—The development of an *x*-ray plate is carried out in several stages. As a rule, it is better first to immerse the plate in water. Wetting the plate thoroughly enables the developer to flow over the plate evenly and prevents the mottled appearance which would occur if certain spots on the plate were left bare of developer for a time while chemic action was already taking place on adjoining parts. Some other operators prefer to slide the dry plate into the developer and cover it completely by a wave-like motion. The second part of the process keeps the plate in the developer for the necessary length of time. It is important at the very beginning of this stage to go over every bit of the surface of the plate, of which the film side should be up, with a tuft of cotton or the finger-tips. In this way adherent air-bells are removed. If these were left the chemic action of the developer could not take place at those points and in the finished plate we should see a number of transparent spots. These appear as inky black spots upon the print or finished picture. A picture may be spoiled by such "pin-holes." Fig. 533 shows the plate before development. It is a dead white and as opaque as thin porcelain. After a certain length of time in the developer an "image" becomes visible upon the plate; it is produced by the part of the plate more directly exposed to the x-ray darkening under the action of the developer. The subject of the picture shows at first as a white silhouette; for instance, if it is a hand it shows merely the white hand without any indication of the bones. As the development progresses the portion of the plate affected by the x-ray, which has passed through the soft parts, darkens up somewhat and we

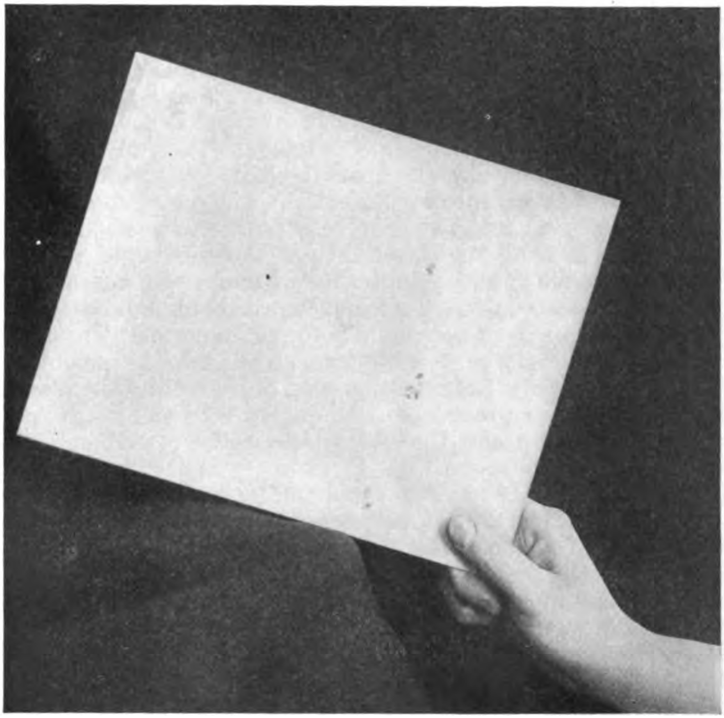

Fig. 533.—Plate which has been exposed, but not yet developed.

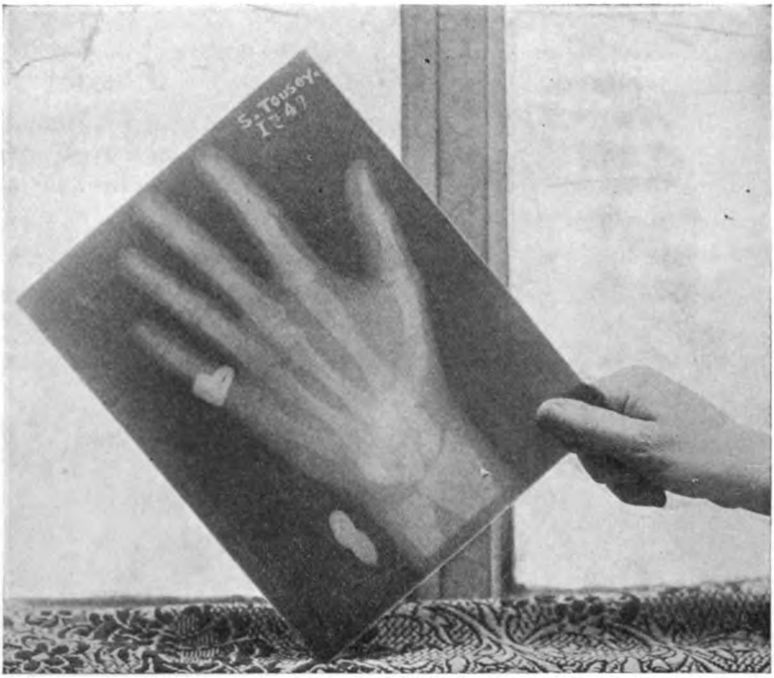

Fig. 534.—Plate after development, but before fixing in the "hypo." It is still opaque and its back is milky white.

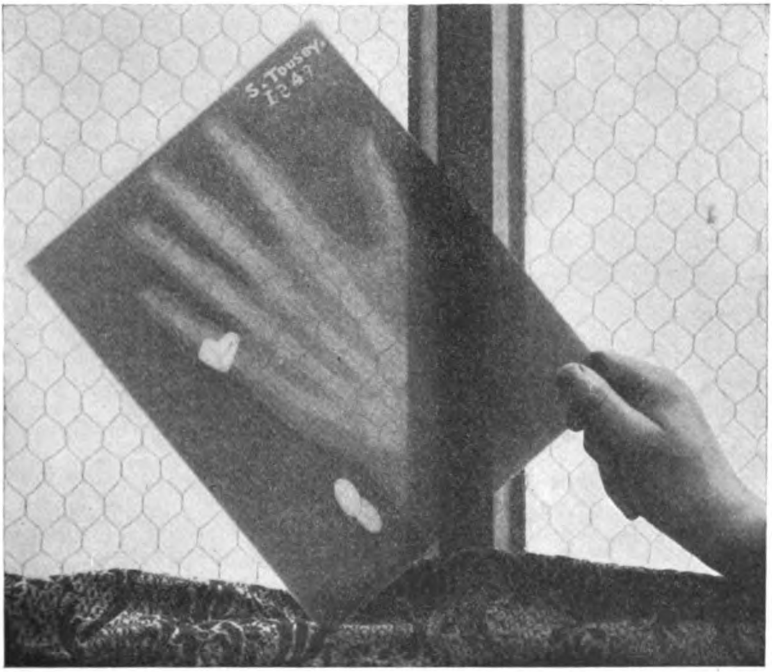

Fig. 535.—Plate after development and fixation. The "hypo" has removed every trace of milkiness and the thinner parts are transparent.

have three general shades; the comparative whiteness of the bones, or any foreign body, the moderate darkness of the flesh, and the blackness of the bare portion of the plate. The bare portion of the plate increases in opacity, while the part covered by the object remains translucent. The image, therefore, is visible by transmitted as well as reflected light. Fig. 534 shows the appearance of a plate after development and Fig. 535 after fixing. The latter process dissolves out the unchanged silver salt and makes the plate lose its dead white appearance and become perfectly transparent at the places where the tissues were densest and the plate was least affected by the *x*-ray. Fig. 536 is the radiograph whose development has been depicted in the previous figure. It would have been better for longer development. It is a fatal error to stop the development too soon. In that case you have a thin plate possibly with plenty of detail, but one from which it is impossible to make a good print. As the development

Fig. 536.—Print from finished plate. The latter was somewhat underdeveloped.

proceeds the portions of the plate which represent the shadow of the flesh and bones become darker, and the image appears to be fading out. This is very apt to frighten the beginner, but it is just exactly what should happen; if the development is stopped before the bones have darkened to some extent the resulting picture will give merely a silhouette of the bones without the structural detail which the best x-ray work should show. Even if the image disappears entirely and the plate appears entirely black the picture of the bones is still there and, perhaps, with more detail than could have been obtained with a shorter development. In a general way, anything that appears fairly white on the plate at the end of development will be absolutely transparent on the finished plate and quite black on the print, if the remainder of the plate has good density. The ideal x-ray picture is one in which the lights are white and the shadows black. To accomplish this the tube must have the right degree of vacuum and must give a sufficient intensity and have a degree of penetration which passes through the soft parts, but casts a deep shadow of the bones, and, of course, the exposure to the x-ray must be of sufficient duration. Given these conditions the development should be carried on until the darker parts of the plate are opaque to transmitted light and, therefore, have the requisite density, but should usually not be carried far enough to completely wipe out the visible image on the plate. Determining the density of the plate by holding it up between the operator and the light and looking at it by transmitted light is not desirable with x-ray plates which are affected by exposure to the red light. Short development is required to show the soft parts of the extremities as well as the bones. The longest development is required for the spine and pelvis and hip-joint, and in these cases the soft parts may be so dark on the plate as to show practically white on the print. In other words, with a pelvic picture some parts of the plate have been very slightly acted upon by the x-ray, which has had to penetrate 6 or 8 inches or more of flesh and bone, whereas other parts have received the direct rays from the tube, or rays only slightly impeded by passing through an inch or two of flesh at the outer limits of the body. During the full development required to bring into view the faint image impressed by the denser parts of the body, the other portions of the plate darken up by receiving what amounts to over-development, and thus, in the finished picture of the hip-joint, for example, the flesh forms a slightly shaded part of the general background. The real picture in this particular case is formed of the bones alone.

Extent to which Development Should be Carried.—No certain number of minutes may be usually depended upon, either for tray-development with a strong developer or for long, weak tank development. Differences in exposure necessitate variations in the time of development, and, generally speaking, the most satisfactory plątes of films are those which are fully developed in five or ten minutes in a strong developer or from one-half to two hours with tank development.

Dental radiographs upon positive cinematograph film should be developed until the image is clearly visible upon the back of the film, and has begun to fade upon the front it is necessary that details should be seen.

The cardinal principle is that where the plate remains perfectly white no details will be found, nothing but total transparency, that where the plate is moderately darkened every detail will be visible, and where the plate is black the density will be so great that the plate is opaque and details are lost. The latter condition is commonly seen upon the portion of the plate outside the image of the patient.

The next part of the process consists in "*fixing*" the image on the plate. This is done by soaking the plate in an "acid hypo" solution for about half an hour; until five minutes after all traces of "milkiness" have disappeared from the film. Following this the plate is to be washed in running water for about an hour to remove all traces of chemicals, especially the hypo, which would cause irregular blotches to appear on the plate afterward.

Formula for Acid Hypo:

Water	2 quarts
Hyposulphite of sodium	16 ounces
Powdered alum	½ ounce
Citric acid	½ "

The different ingredients should be fully dissolved in the order given. This constitutes not only a fixing bath but also a hardening solution which prevents softening or frilling of the film during the subsequent washing. This can be used several times, adding hyposulphite of sodium to it when it becomes exhausted.

The plate should be carefully washed off, using the finger-tips or a very soft sponge to remove particles of sediment from the film surface, and real rubbing to remove a tough black film which is found in spots near the edges of the glass or back surface. Then the plate is set in a drying rack in a place where dust will not be likely to catch upon the moist gelatin surface of the film.

If a *kodak* or similar *celluloid film* is used the process of development is the same, but at the end a couple of pins are stuck through the corners and the film hung up to dry.

In any case the *excess of moisture* had better be wiped off before the film surface has begun to dry. Tear drops on the plate and a line of water at the bottom of the plate make the film dry more slowly and cause darker areas in those places.

The **chemistry of photography** is interesting. The dry plates or celluloid films are coated with a gelatin or other emulsion containing nitrate and bromid of silver, and when this is acted upon by light the silver compounds become more easily acted upon by agents which seek oxygen. The developing solutions contain such agents and on the portions of the plate acted upon by light metallic silver is deposited by the abstraction of oxygen from the original chemic compounds. This produces a visible image, whereas none was to be seen when the plate was first looked at in the dark room after exposure either to light or to the *x*-ray. But this image has to be made permanent by the process of fixing, which consists in soaking in a solution containing hyposulphite of sodium; this dissolves away all the unchanged silver compounds.

The **choice of developers** is important. The old standard developing agent is pyrogallic acid, and probably one can make a greater number of good plates with all sorts of normal or under- or overexposures by its use than with any other. It makes a brownish colored plate which prints better than the black or gray plates produced by most other developers. About the only objections to it are the facts that it stains the hands badly and that it cannot be used for developing the print also.

A good formula for a *pyro developer* is

Solution A.—Water		16 ounces
	Pyrogallic acid	1 ounce
	Oxalic acid	10 grains
Solution B.—Water		16 ounces
	Dried sulphite of sodium	2 "
Solution C.—Water		16 ounces
	Dried carbonate of sodium	2 "

Use Solution A, 1 oz.; Solution B, 1 oz.; Solution C, 1 oz.; water, 7 oz. Developing factor 12.

By "*developing factor 12*" we mean that if we note the time from placing the plate in the developer until the appearance of the image and multiply that time by 12 we shall have the time required for complete development. With this developer a normal exposure will show an image in twenty to forty seconds and, consequently, only two to four minutes' development would be required. If an image does not show at all after a minute or so the plate has been underexposed, and it may be wise to pour off the developer and treat the plate as we would have if we had known beforehand that it was underexposed.

For a known *underexposure* an excellent way is to use the soda solution alone at first: Solution B, 1 oz.; solution C, 1 oz.; water, 7 oz.; allow the plate to remain in this for about half an hour, then pour the solution off and add to it solution A, 1 oz., and use the complete mixture for ten minutes. At first an image becomes visible from the action of the soda solution, but it is faint and soon disappears, the entire plate blackening up. During the rest of the process the plate is just black all over and it is not until after it is removed from the hypo, and can be examined by looking through the plate in ordinary daylight, that the image can be seen. It may then be found to be very good indeed and may make an excellent print. Generally speaking, the pyro makes density and the soda detail, and if the complete developer were used for the length of time required to produce a good image with underexposure the pyro would make the plate too dense all over or fog it.

The term *fog* is used to designate a universal or localized increase in density of the plate, produced by extraneous causes and obliterating the natural lights and shadows of the picture. Fog may be produced in an *x*-ray plate by allowing the plate to become light struck, for instance, by keeping the plates in too bright a light, which may penetrate even the black and orange envelopes in which *x*-ray plates are usually kept, or by white light entering the dark room, or by too much exposure to ruby light during development, or by accidental exposure to the *x*-ray at some other time than when the picture was being made. Chemic fog may be caused by adding new or strong developer to that in which the plate already is, thus subjecting the plate to the action of an imperfectly mixed developer; or, as intimated above, by development with too strong a developer.

Another way with underexposed plates is to use a very weak developer for a very long time, as in "*tank development.*" In this process the plates are placed in vertical grooves in a hard rubber or nickel tank (Fig. 537), filled with a developer of about $\frac{1}{16}$ the normal strength and containing potassium or ammonium bromid, to act as a further restrainer, and the plate is left soaking in it for seven to twelve hours. The same process gives excellent results as to details in cases of normal or overexposure if one has time to wait for the results. For a normal exposure about two and a half hours and for an overexposure about an hour would be approximately the time required for tank development. But in the case of normal and overexposure the plate must be looked at from time to time and the process brought to a close when the plate is completely developed. Remember in every case that there is very little to be lost by keeping the plate in the developer too long, and there is everything to be lost by taking it out before the plate has gained sufficient density. In some cases development is not complete until the original white image at first produced has almost faded out. An overdeveloped plate will still make an excellent print, while one underdeveloped is worthless. The fading out of the image during development does not imply that it is actually disappearing.

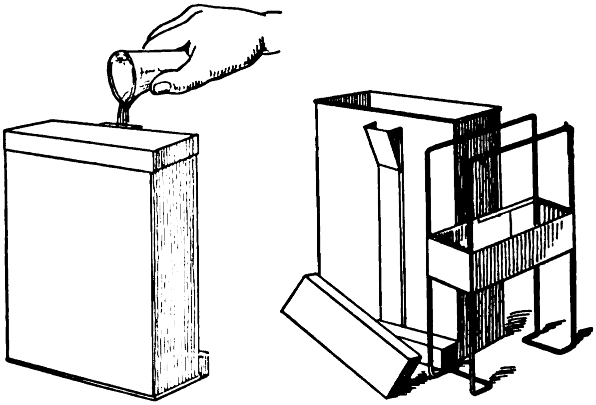
Fig. 537.—Tank development.

One very good guide in developing all single-coated plates and films is the presence of an image on the back of the plate. This usually shows complete development.

Tank Developing.—A good formula for this purpose is the following:

Stock Solution

Water	32 ounces
Carbonate of sodium (dried)	2 "
Sulphite of sodium (dried)	1¼ "
Bromid of ammonium	30 grains
Citric acid	30 "
Hydroquinone	60 "
Glycin	2 drams
Metol	2 "
Pyro (pyrogallic acid)	4 "

Dissolve the ingredients in the given order and keep the complete mixture in 6-oz. bottles, full and tightly corked.

For use in developing a number of 8×10-inch plates take 6 oz. of this stock solution and 10 pints of water, filling the tank.

Immerse the plates in cool water before putting them in the tank. Give them a quick up-and-down motion after placing in the tank to remove air bells. Take them out of the tank after a few minutes and reverse their position; this is to prevent streaks from the solution being possibly stronger at the bottom of the tank. Occasionally rocking the tank is of great service in preventing spots and streaks.

Several plates of the same or of different sizes may be developed in the tank at the same time. A cover is placed over it so that the room need not be kept dark during the entire time, but only from time to time when one or more of the plates are ready to be taken from the developer and placed in the hypo.

I believe thoroughly in tank development for instantaneous exposures and other work where the plate may be described as underexposed.

Tank Development for Films.—The small films used in dental radiography may be developed in a nickel-plated tank measuring 2×4×6 inches and requiring less than a pint of developer.

Each film may be fastened by adhesive plaster at all four corners to a glass plate measuring 3¼×4¼ inches. The plates are put in a rack and immersed in plain water to wet the films thoroughly and then set in the developing tank full of developer. This must all be done in the dark room by red light, but after the cover has been put on the tank the operator may open the dark room and then leave the films for about twenty minutes. This is the time required for normal exposures and if one is sure of uniformity as to the exposure it is only necessary now to pour out the developer by ordinary light without opening the tank after twenty minutes' development and pour in the acid hypo. The fixing takes about fifteen minutes and then water may be allowed to run through the tank for half an hour. This removes the hypo from both the films and the tank. A nickel-plated tank may be used for all three of these processes, whereas a zinc tank could not be used for the hypo; this solution acts upon zinc. When it comes to drying the films they must be unfastened from the pieces of glass and hung up to dry in the usual way.

The M. Q. Developer.—The metol hydroquinone developer has come into very general use for developing dry plates and celluloid films and also for velox and bromid paper and similar prints. It is easy to handle, does not stain the fingers badly, and gives a clear black plate which is very handsome and which has almost as good printing qualities as one developed by pyro. Its disadvantages are the slowness with which it acts, and the greater difficulty of exactly regulating the development to get the best results out of different plates with all sorts of exposures. It is sold everywhere in tubes, each of which contains enough to make 8 ounces of developer by simply dissolving in water. For a normal exposure the plate should be developed for fifteen or twenty or thirty minutes in a fresh developer. If the image flashes up and the plate seems to be overexposed either promptly add 5 or 10 drops of a 10 per cent. solution of bromid of potash as a restrainer, or else pour off the developer and use an old and partly exhausted developer. If no image is visible in five or ten minutes the plate has been underexposed and is going to require prolonged development in a weakened developer. An ordinary hip-joint picture requires about one hour's development in M. Q. developer which is not entirely new. A picture of the foot would require about half an hour's development. Most of the radiographs in this book were developed with M. Q. developer in a simple flat tray, and probably it will be found best to use this as a starting point, and then to add the tank development and the soda followed by pyro development as one's general technic improves.

Other good developers are:

Eikonogen-hydroquinone

A.—Water	48 ounces
Sulphite of sodium (dried)	2 "
Eikonogen	240 grains
Hydroquinone	60 "
B.—Water	16 ounces
Carbonate of sodium (dried)	2 "

Use *A*, 3 ounces; *B*, 1 ounce. Factor 12.

Ortol

A.—Water	24 ounces
Potassium metabisulphite	90 grains
Ortol	180 "

Use equal parts of *A* and *B*. Factor 11.

These are practically the same as recommended by the M. A. Seed Dry Plate Company, St. Louis, Missouri.

Pyrocatechin

A.—Sodium sulphite crystals	750 grains
Pyrocatechin	150 "
Water	16 ounces
B.—Caustic potash	110 grains
Water	16 ounces.

Use *A*, 1 ounce; *B*, 1 ounce; water, 4 ounces.

The special advantage claimed for pyrocatechin is that it can be used in cases requiring prolonged development without fogging the plate.

The Titubator.—This is a useful apparatus in which the plate in a tray full of developer is placed in a light-proof box and by an electric motor is subjected to the gentle rocking required. The plate must be placed in the titubator in the dark room, but the thirty minutes or so of rocking may be done by the closed machine in any ordinary light.

The Influence of the *x*-Ray Upon Plates During Development.—The *x*-ray should not be in operation in the same room or in an adjoining room. An ordinary lath and plaster partition is perfectly transparent to the *x*-ray and during the prolonged development, so often required by *x*-ray plates, they would be sure to be fogged. The same is true even if the plates are in sheet iron (galvanized or tinned or japanned) trays, but if the developing trays are completely surrounded by a box of *x*-ray metal, lead and tin, the plates are safe. The protection should be at top, bottom, and sides; but, of course, it is understood that even with this it would not do to allow the *x*-ray to shine directly upon it at short range.

Making Prints from *x*-Ray Plates.—The print is the finished picture on paper. It is made by placing the film side of the paper in contact with the film side of the plate, allowing ordinary light to shine through the plate, the varying density of different parts of the plate producing the lights and shadows of the picture on the sensitized surface of the paper. In the case of Solio and other printing-out paper the image is visible upon the paper before any further treatment is given to it, and the printing, or exposure to light, is continued until the print is dark enough. The printing frame opens in sections, so that one part of the print may be inspected from time to time without disturbing the relative position of the paper and the plate; just like opening a book and closing it again. These papers require brilliant daylight and take from a few seconds to half an hour or more to print, depending upon the density of the plate. They may be made by the electric arc light, but not by the incandescent light. The print should be made several shades darker than you wish it to finally appear, as it fades to some extent in the different solutions. It is first washed in five or six changes of water to remove the unchanged silver and then placed in the

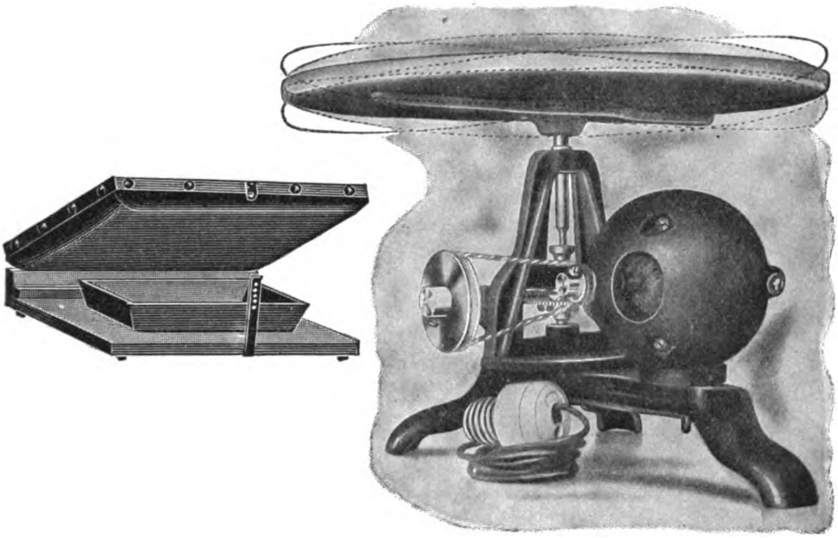

Fig 538.—The Kelley-Koett developing titubator.

Toning Solution

Chlorid of gold	1 grain
Water	48 ounces.

Bicarbonate of sodium sufficient to produce a neutral reaction.

The print should tone in about six or seven minutes, during which time a chemic change takes place in the film whereby a deposit of metallic gold takes the place of the silver compound on the surface of the paper. At the same time the color of the picture changes from reddish to a rich purplish brown. Failure to produce this change in color would indicate a worthless toning solution.

The print is then washed in water and placed for twenty minutes in the acid hypo, where the image is made permanent and the film hardened. The formula for this is almost the same as the one recommended for fixing plates.

Acid Hypo for Solio Prints

Hyposulphite of sodium	6 ounces
Alum (crystals)	2½ "
Sulphite of sodium (crystals)	⅜ ounce
Water	70 ounces.

All traces of the hypo should be removed by washing for an hour in running water.

Prints Made from Plates or Films Which Are Still Wet.—It is occasionally desirable to obtain a print at once without waiting for hours while the plate or film dries. While the sensitized surface is still perfectly wet a sheet of photographic paper, also wet, is laid upon it. The two sensitized surfaces are face to face and gentle pressure is made to squeeze out any bubbles of air which may be trapped between them. The print is made in the usual manner, but is not quite so clear as if made with dry paper and a dried film or plate. The plate or film is not injured if this is carefully done.

In *mounting prints* on cardboard the first thing is to dry the prints and trim them, then wet them and pile them one on top of the other face down on a sheet of glass. Squeeze out the excess of water by means of a piece of blotting-paper and a print roller. Cover the back of the topmost print with photo paste, lift up the print by two opposite corners, and place it in position upon the card and rub it down smoothly with the print roller.

Velox paper and other similar papers require only a few seconds' exposure to gas or electric light at a distance equal to one and a half times the diagonal measurement of the plate. No image is perceptible until the paper has been placed in the developer and, hence, these are called *developing-out* papers. The M. Q. developer used for developing plates gives excellent results with these papers and the same acid hypo fixing solution may be used. In using these papers it is necessary to determine by trial with slips of paper the exact time of exposure to be given. If the exposure is too long the paper blackens up in the developer and all detail in the picture is lost. If the exposure is too short no amount of time in the developer will produce a good print.

Bromid papers are handled in the same way as Velox, but are much more sensitive and, hence, print in a much shorter time of exposure. They are advantageous in making prints from very large plates because the image comes up gradually while they are in the developer, more like that on a plate, instead of flashing up all at once like the image on Velox. It is, therefore, easier to secure a perfect print.

With all the prints it is necessary to wet the paper thoroughly before putting it in the developer and then to see that the developer instantly and uniformly covers all parts of the print, otherwise the print will have spots and streaks of darker or lighter color showing uneven development. The print must be taken out of the developer at just the right instant, and if there is time should be rinsed in water before placing in the acid hypo. The paper should not be creased and crumpled, as this will be sure to cause a separation of the sensitive film or coating and the formation of blisters. These also result from letting a stream of water strike directly on the film surface and, especially, from putting the print into water or solutions which present too great a difference of temperature.

The process of making and developing all except bromid prints may be carried on by ordinary light in quite a darkened room.

In making a *print from a large plate* it will sometimes happen that one part of the plate is thinner and prints more rapidly than another, and in such a case the thinner part should be held further from the light or else covered up during part of the exposure. If covered it must be by some object which is kept in constant motion to prevent a line of demarcation.

Printing from a Thin Plate.—Where the details in a thin and almost transparent part of the plate are desired the print should be a light one. The ordinary length of exposure to light in making the print would make all this part simply a black mass.

Bromid Prints Directly from the Patient.—By this method a finished paper print is made inside of five minutes. One or more sheets of bromid paper are placed inside a light-proof envelope and used exactly like a plate in taking an x-ray picture. The paper is developed just like an ordinary bromid print, but shows the bones white, the flesh whitish, and the background gray or black. The process is one that does not require a dark room and saves a very great deal of time. You get a print in five minutes as against about twenty-four hours by the plate method. This is much sooner than even a wet and only partially finished plate would be ready for examination. It is useful, for instance, in examinations for a needle in the hand or for a fracture about the hand. In these cases a fluoroscopic examination often fails while the picture succeeds. Then again, the picture can be examined and discussed ad libitum, whereas a consultation while examining with the x-ray is a source of very great danger from too long exposure. With a 12-inch induction-coil and a primary current of 18 amperes (intensity No. 15 Tousey, penetration No. 6 Benoist), a picture of the hand by this method would require an exposure of about twenty-five seconds. Such a picture taken at a meeting of the Middlesex County Medical Society of New Jersey showed the barb of a fish hook which had been in a doctor's finger for thirty years. The method is especially available for the extremities and for dental skiagraphy. The best results are obtained with exposures two or three times as long as are required for a plate, and this makes it less useful for the thicker portions of the body.

Plastic radiographs are prints to which an artificial appearance of perspective is given. A process was suggested by Alexander and perfected by Schellenberg. It consists, essentially, in making a radiograph upon a single photographic plate, then making a print from this on a transparent film. The finished print is made from both plate and the transparent positive film, placed one on top of the other, but not exactly coincident. A very simple and easy process is to use what is technically called *bromid negative paper* for the first positive print from the original plate. This paper, after development, is rendered transparent by immersion in an oily substance, and can then be laid upon the original plate and a print can be made upon any ordinary velox or solio papers. Such pictures may have certain uses, but they do not give any true stereoscopic effect.

Alexander's Method of Plastic Radiography.—Dr. Bula Alexander[1] describes a method which consists in making as good a negative as possible on Plate I. From this a diapositive is made on Plate II by allowing ordinary light to shine through Plate I while it is face to face with Plate II. The second plate is developed and shows an image with the lights and shadows reversed. Plates I and II are now fastened together back to back and with their images almost coinciding, and a diapositive is made on Plate III. This plate gives the effect of perspec-

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[1] Arch. of the Röntgen Ray, January, 1908, and several previous articles in Budapesti Riv. Orvosegyesulet, 1906, etc.

tive and also, it is claimed, an increased definition of the bones and soft parts. It does not exaggerate or reduce the apparent size of the bones. Plate III is a positive and if it is desired to secure a print of the ordinary kind in which the bones appear dark, still another, Plate IV, must be made from it. As many prints as desired may be made from Plate IV. If only one print is desired it may be made instead of Plate III. Fig. 511 is such a plastic print from a frontal sinus and ethmoid and antrum radiograph. It looks a little like a picture of a plaster-of-Paris cast, and shows that the plastic method is of comparatively little value in depicting the ethmoid cells and the antrum, but that it makes the frontal sinus more conspicuous.

Radiographs of the extremities are improved by this method except where a number of small bones are crowded together, as in the carpus.

Stein[1] has also described a method for plastic radiography.

Precautions to be Taken in Developing Radiographs.—A trace of hypo, remaining on the plates or prints, will make a brown stain which will spoil the whole work. Eternal vigilance must be used with this and all the other chemicals. There must be a special tray for the hyposulphite of sodium solution and when through with it the solution must be filtered back into its own bottle. Running water should be constantly ready and the fingers should be washed every time they have been in any of the chemicals. Keep up a rocking motion of the trays in which plates or films are being developed. Do not let one lie on top of another, as that would scratch it or prevent the uniform action of the developer on all parts of it.

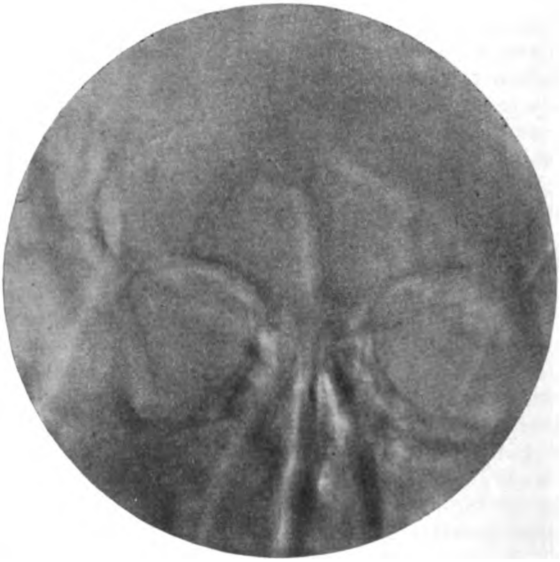

Fig. 539.—Plastic radiograph of the frontal and other sinuses of the face.

From beginning to end the plates and celluloid films ought never to see a particle of white light or of x-ray except during the actual taking of the picture. They ought to be exposed just as little as possible to

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[1] Münch. Med. Woch., July 31, 1906.

ruby light in the processes of placing them in the opaque envelopes and later placing them in the developer. While in the developer they ought to be in absolute darkness, except for occasional examination by the ruby light to note the progress of development.

A very important point is not to touch the film surface during the different manipulations. A touch with the finger is apt to leave an "opaque finger mark" on the plate which ruins that particular part of it. This would show in the print as a white smudge.

Generally speaking, if a beginner watches the development of a plate he is apt to underdevelop it; fearful of losing the image altogether when he sees it begin to fade out upon the surface of the plate. This fading simply means that that portion of the plate also is beginning to be developed as well as the background which was directly exposed to the *x*-ray. If this is stopped much too soon, of course, you fail to get any detail in the picture, and may hardly see the bones in the flat appearing image of the flesh. If the development is stopped only a little too soon you may get a plate with good detail, but so thin and transparent that it makes a very faint print. On the other hand, a little overdevelopment does no harm at all, it simply means that you have to hold the finished plate up toward a bright light to see the image, the print made from it is perfect. A plate very much overdeveloped is almost jet black and opaque, and must be held up to a very powerful light, like the Cooper Hewitt light, in order to see the image; and a print from it shows only the bones. The flesh and even thinner portions of bone may not show at all in a print from such a plate. The print is also a harsh black and white.

Restraining the Development.—A plate on which the image flashes up almost immediately when it is put in the developer has usually been overexposed, and if developed in the ordinary way soon turns black and will be so dense that the picture can hardly be seen at all. Such a plate would take a very long time to make even a poor print from; and it could not be studied by transmitted light unless one had a very powerful electric lamp. One may know from the length and strength of exposure to the *x*-ray that the plate is overexposed. In case this fact is only discovered when developing the plate the latter may be quickly transferred to plain water and then developed in an old developer weakened by previous use, or in a developer weakened by dilution with water. Another method is to quickly add "Restrainer" to the developer. The restrainer is a few drops of a 10 per cent. solution of bromid of potassium.

The object in restraining the development of a plate is to obtain sufficient detail without excessive density. The details depend upon slight differences in density which can only be brought out by slow development and moderate density.

A plate which is known to be overexposed is developed from the start in old or dilute developer or one to which restrainer has been added.

Overexposed Plates Which Should Not Be Restrained.—Radiographs of the head, abdomen, or hip are usually overexposed at the edges where the *x*-ray shines directly on the plate, but the central and most important part of the plate is underexposed rather than overexposed. The development should not be restrained, but the loss of detail near the edges of the picture should be accepted as a necessary evil. In some cases the overexposure at the edges is so great as almost to wipe out even the image of the sheet lead numbers laid on the plate for identification. Though these may not be seen in the print they are always traceable when such a plate is examined by transmitted light. The central part of such a plate may come up nicely with normal development or it may require to be treated as an underexposed plate.

Full Development and Subsequent Reduction of Overexposed Plates.—This will often result in a beautiful plate, with detail and contrast, when from accident or design the plate is overexposed. In the words of an expert friend of the author, "if a plate flashes right up leave it in the developer and forget it for fifteen minutes." The result is a completely blackened plate which, when it comes out of the hypo, may be reduced by immersion for from five to fifteen minutes in a weak solution of permanganate of potassium and sulphuric acid and then washing in water. If the plate has a yellow stain, this may be removed by immersion in a solution of citric acid and sodium sulphite.

Development of Underexposed Plates.—If there is only slight underexposure the development may be simply forced. A full strength and entirely new developer may be used and the development continued for a longer time than usual. Care must be used not to carry this process to excess or the plate will be badly fogged.

Forced Development.—In developing *x*-ray plates or films it is at times necessary to force the plate in developing. The following formula, used by the H. N. Tiemann Co. for many years, gives a good black tone, and enables one to force a plate for a half to three-quarters of an hour before it will stain or fog. Dissolve:

2 ounces sulphite soda crystals.
2 ounces carbonate soda crystals.
½ dram bromid potassium.
Use distilled water, hot, to make 16 ounces.

After sodas are dissolved mix:

2 drams hydrochinon.
1 dram metol.
2 drams pyrogallic acid.
Dissolve these in 8 ounces of distilled water, hot; then add to the sodas. We now have 24 ounces of solution; use full strength after cooling.

Marked underexposure requires long and slow development in a weak developer until the details are brought out and then forcing. Tank development is excellent in this case, and so is the process by which the plate is immersed in the sodium sulphite solution for several minutes and then in the pyro solution. In spite of all this manipulation the finished plate may be found too thin or the image too faint; and intensification may be resorted to.

Development of Screen Plates.—Radiographs made with an intensifying screen are more like ordinary photographs, and a special developing formula is given on page 764.

Intensifying *X*-Ray Negatives.—This process may be applied to a plate or film at any time after complete development and either before or after drying. The usual method is to immerse the plate in an intensifying solution, such as

Mercury bichlorid	220 grains
Potassium bromid	130 "
Water	7 ounces

until the entire plate has turned white, and the picture shows upon it like a positive. The longer the plate is left in the intensifier the denser the negative will be.

The next step is to wash the plate in running water for about half an hour.

Then the plate is immersed in

Sodium sulphite	1½ ounces
Water	6 "

until it has all turned perfectly black.

A final washing in running water completes the process.

Yellow stains indicate incomplete washing after the mercury bichlorid bath.

The process of intensifying gives added density to every part of the plate in proportion to its original density. This increases the contrast between the parts but slightly affected by the *x*-ray and the other parts which are decidedly affected.

Intensification is a perfectly legitimate expedient, but it has not been adopted in making any of the radiographs in the present volume, and the author always tries to avoid the necessity for it by employing an exposure which will give a good picture with normal or somewhat forced development.

It is useful for underexposed negatives and also for certain overexposed negatives. In the latter case the plate has sometimes been kept from becoming too dense by the use of restrainer or very careful development; but still a print from it presents scarcely any contrast. This defect may sometimes be remedied by intensification of the finished negative.

The results are very much better if the exposure can be so regulated that normal development suffices.

The Choice of Developers.—As a general thing there is very much to be gained by using the developing formula recommended by the manufacturer of the plate or film. An example of this fact was lately brought to the author's attention. A friend had been using a certain film on his recommendation and with excellent results. After about a year the quality of the pictures suddenly underwent a radical change. The same subjects that formerly required an exposure of ten seconds now required forty seconds, and the pictures were lacking in brilliancy and contrast. After considerable correspondence with the company, it transpired that they were using a new emulsion on these films and that they recommended a different developer from the one that he had been using. The moment that the right developer was used the results became as good as with the old films.

Development in Tropical Countries.—The usual developing solutions must be used at a temperature of about 65° Fahrenheit and can only be used if ice is available. Where it is impracticable to keep the solution at about this temperature means must be adopted to harden the sensitized coating of the film or plate. This is done by immersion in a solution of formalin. The developer must also be somewhat different from the normal one.

Tropical Developer (*Kassabian*)

Water	50 ounces
Sulphite of sodium (crystals)	2 "
Bromid of potassium	20 grains
Citric acid	20 "

For use: To 4 oz. of the above solution add 10 grains of dry amidol. Before developing, place the plate in

Water	60 parts
Formalin	1 part

for about three minutes, rocking the tray occasionally, then rinse well and place in the developer. If the image flashes up in less than forty seconds add more of the potassium bromid. Development should be complete in four minutes if the exposure has been normal.

The Explanation of Some Defects in Developed Plates.—Sometimes the *film is washed off* the plate, leaving perfectly clear glass at the edges, shading gradually into the pictured part of the plate. This is apt to occur with a developer that is a little too warm if the plate has to be left in it for a long time and has to be handled much. Carried to an extreme, the whole picture would be washed off the plate.

The sensitized coating of the plate may be full of *cracks* running in every direction and dividing the surface into numerous sections. This condition is usually due to the use of too warm solutions for developing, fixing, or washing the plate.

There may be a general *mottling* which produces quite a regular pattern in the picture, somewhat like the design known as marbling in decorative art. This occurs when a strong developer like pyro is allowed to act without stirring. It can be avoided by keeping the developing solution in motion by rocking the tray, or by the use of the titubator, or, if a large heavy tray is used which cannot be conveniently kept in motion, the solution can be kept in circulation by moving the finger-tips about in it. A very weak developer, such as is used in tank-development, has not much tendency to produce this defect, because in the long time that the plate is immersed in the solution it has an opportunity to permeate the film uniformly. Even then it is safer to take precautions against it. The plates should be taken out of the tank after a short time and put back the other side up; and the entire tank should be shaken from time to time.

Pin-holes result from the adherence of air-bells to the film surface. These prevent the action of the developer and leave perfectly transparent spots upon the plate. The means of prevention is to wipe off the surface of the plate lightly while it is in the developer. Moving the plate up and down a few times accomplishes the same result in tank-development.

Brown stains upon the plate are of several different kinds. A mottled or streaked metallic sheen over the whole or a part of the plate impairs the value of the plate to some extent. It is a deposit from the developing solution and may be removed in great part by wiping the plate, before drying, with a tuft of wet absorbent cotton.

Another kind of brown stain comes in large spots some time after the plate has been dried and put away for storage; it is due to imperfect removal of the hypo. Prolonged washing in running water prevents this occurrence which permanently damages the plate.

Sometimes a plate will be found to be covered with a *sandy substance,* which would interfere with the clearness of the picture if allowed to dry on the film surface. This is due to the use of a hypo solution which has not been filtered. It may be prevented by filtering the hypo solution, or it may be removed after it has occurred by wiping the plate, before drying, with a tuft of wet cotton.

Frilling of the film, or separation of the sensitized film from the glass near the edges, is due to the use of too warm solutions. There is no remedy for it afterward. The only thing is to guard against it by using solutions at a proper temperature, or, if this is impracticable, to adopt the measures described under "Tropical Development."

The whole or a large part of the sensitized film sometimes separates in a continuous sheet from the glass plate or from the celluloid film. If this occurs with perfectly normal development it is suggestive of an imperfection in the plate or film and a new supply should be obtained. This has happened once or twice in the author's experience. Once was quite recently with a very thin celluloid film which was not of the non-curling variety.

The presence of *great blotches* upon the plate may be due to two different causes: *first,* immersion in a strong developer without previously wetting the plate thoroughly with plain water and without taking pains that every portion of the plate is immediately completely wet with the developer; and *second,* some defect in the plate which makes parts of it less sensitive than other parts.

A general mottled appearance, coming as a sort of *fog,* if the plate is underexposed and requires prolonged development, is more apt to occur if the plate is old; and many an abdominal picture will prove a failure if plates several months old are used. A plate becomes more sensitive and hence more rapid with age, but the change is not an absolutely uniform one. There is no means of improving such a plate. The only prevention is to use fresh plates. This is one great drawback to the use of special x-ray plates except in the largest cities. There may not be sufficient demand for them to enable the dealer to keep an absolutely fresh stock. The best plates for daylight photography give results which are practically identical with those obtained with x-ray plates, and every dealer carries a fresh supply of them. The same x-ray plates which present this kind of fog from being too old may give perfectly good pictures of the hand or any part where the x-ray effect is so strong that only normal development is required, and the differences in the degree of sensitiveness of certain spots on the plate are not discoverable.

A 14 × 17-inch plate means quite a loss if it has to be thrown away, and still this size is only used for the largest portions of the body and requires prolonged development. It is unwise, therefore, to use one for this purpose if it is more than two months old. The plate, however, may be cut up into smaller sizes and used for radiographs of the extremities. It would not be wise to try to make a frontal sinus picture on a piece cut from such a plate because the same conditions prevail here as in radiography of the abdomen.

Cutting Photographic Plates.—This is done by drawing a line on the glass—not the film—surface with a glass cutter and then bending it away from the scratched surface. This can be readily done before the plate has been developed; but the latter process makes the film so dense and tough that one is very likely to break the plate into several pieces, instead of breaking it along a straight line. Still it sometimes happens that there is just a small part of a large developed plate which one wishes to cut out.

To *cut a developed plate* one should scratch all the coating off a broad line of the film surface and then draw a line along this bared surface with the glass cutter. The plate is broken by bending it away from the diamond scratch on the film surface.

Too strong developer causes the image to flash right up, soon darkens the whole plate, and obliterates the finer shades.

Too long development obliterates the details. A print from such a plate is poor. The plate turns gray or bluish gray.

Scratch-marks on the finished plate may ruin an excellent picture. They come from even very slight rubbing of the sensitized surface at any time before development. Friction which may not be nearly sufficient to scratch through the film and expose the glass plate will, nevertheless, so affect the sensitiveness of the film as to make an indelible mark on the finished plate and any prints made from it. There is only one way to prevent this accident and that is not to touch the sensitized surface with any hard substance until after it has been developed and dried. The finished plate is quite durable and will stand any ordinary handling, but if it is to be used a number of times for purposes of demonstration it had better be protected by varnish.

Varnishing the Plate.—A varnish is made for this purpose which dries clear and hard. The plate is held horizontally in one hand while half an ounce or more of varnish is poured over it. This is allowed to flow over different parts of the plate until the entire film surface has been wet and then it is drained back into the bottle. The plate is stood up and allowed to dry in a place which is free from dust.

Perspiration-marks on the Plate.—The ordinary envelope in which *x*-ray plates are used is perfectly permeable to moisture, and the perspiration may strike through from any part of the body which lies directly upon it. The chemic properties of the perspiration cause it to produce a very great effect upon the film, and this is shown as a whole mass of black spots on the finished plate, or white spots on the print. The author makes it an invariable custom to lay a piece of celluloid or paraffin paper or cardboard under the part that rests upon the plate.

The **envelopes** which contain the plates may produce an injurious effect upon the sensitized surface. Ordinary paper contains so much sulphur that it is entirely unsuited for this purpose and even the specially prepared envelopes are not entirely safe. To be absolutely secure against trouble from this source the plates should be kept in the original boxes until just before use, and then should be put in the opaque envelopes in the dark room. Usually, however, the envelopes are safe enough for several weeks, except for some case which results in underexposure and prolonged development; then the slight harmful effect upon the plate may be brought out and may entirely overshadow the picture. The paste which is used to fasten the seams of the envelope has an especially deleterious effect upon the photographic plate, and the plate should always be put in the envelopes so that the smooth side of both envelopes is at the film side of the plate.

The author almost always exposes two plates at the same time, so as to have one to send to the physician and one to retain as a record.

Trouble due to the effect of the envelopes upon the film can be avoided by keeping two plates face to face in the same envelope, being careful not to produce the scratch-marks referred to above.

Sulphur and **moisture** affect photographic films very badly and plates must be carefully protected from both of these. The amount of sulphur present in the air of ordinary dwellings, especially if lighted by gas, is shown by the quickness with which silver tarnishes. The sensitized film is really an exquisitely susceptible silver surface. The same factors occasionally damage the plates and films which are sent across the Atlantic Ocean.

Fogging from *x*-Ray in the Place in Which the Plates are Stored.—The plates should be stored in another room and separated by a brick wall from the *x*-ray tube. Even then they should not be kept on an ordinary shelf, but should be in a lead-lined box, and the cover of this should never be left off when the *x*-ray is turned on in an adjoining room. Ordinary light diffuses into an adjoining room through an open door even if a screen is placed to cut off the direct rays from the lamp; and in just the same way secondary rays arise from every object in the *x*-ray room and any adjoining room not separated by an impenetrable partition such as a brick wall.

The danger of ruining plates or films, which may represent several dollars' worth of material or several hours of labor, by a few seconds' exposure to the *x*-ray is something that should be constantly borne in mind. It is an excellent rule never to bring an undeveloped plate or film into the *x*-ray room at any time except when that special plate is to be exposed for a radiograph. Another good rule is to have the cover of the lead-lined box for plates and films made in such a way that the cover cannot be taken off entirely, and that it will shut of its own weight except when held open by the hand. In this way the box can never be left open accidently. The author uses a wash-boiler, measuring 14×15×24 inches, for storing unused plates and films. He lined this himself with sheet-lead held in place by strips of adhesive plaster.

Storage and Filing of Developed Plates and Films.—The *small films* on which tooth radiographs are made are marked with white ink after development, and all the small films of each patient are put in an envelope marked with the name of the patient and the examination number. Thus, the envelope may be marked "Brown, 1633; 1, 2, 3."

These envelopes are all arranged in numerical order in a card index drawer, but there is also a card index of all patients' names from which the examination number and the size of the plate or film can be learned in a moment.

Each physician referring cases has a card in my card index giving the names of his different patients and their examination numbers.

Larger films up to 5×7 inches are stored in numerical order in a negative film file. The latter looks like a photograph album, but each leaf is made up of thin transparent paper forming a pocket into which a film may be slipped. A hundred films filed in this way take up no more room than a book measuring 5½×8½ inches and 1 inch thick.

Films larger than 5×7 are kept in separate envelopes and filed in pigeon-holes.

Files for Plates Up To and Including 8×10 Inches.—An excellent type of these is sold in America under the name of the Star negative file (Fig. 540). It is made for 5×7-, or 6½×8½-, or 8×11-inch plates and consists of a box 6 inches thick, and long and high enough for the proper size plate to fit in it in a vertical position between pasteboard partitions. The plates require no envelopes and a notch at the top of each partition enables one to see the number marked on the plate in white ink. Each file holds 50 plates and when filled with the largest sized plates (8×10 inches) it weighs only a little over 20 pounds. The smaller ones weigh proportionately less. There is no difficulty, therefore, in lifting them off a closet shelf and carrying them to the light in order to find any particular plate, though it would be more convenient if one had a safe place to store them where there was a good light.

The same vertical files may be used for celluloid films and will hold three or four of these in each section.

Storage of Finished Plates Larger than 8×10 Inches.—The 14×17-inch plates weigh 3 pounds apiece and may be stored in the heavy cardboard boxes in which six of them are originally sold. The number of each of the six plates should be written on the outside of the box, and the boxes should be stored vertically between wooden partitions about 6 inches apart. The way which is adopted by the author is to keep every plate larger than 8×10 inches in a separate envelope, and to file the plates of each size together between vertical board partitions about 6 inches apart.

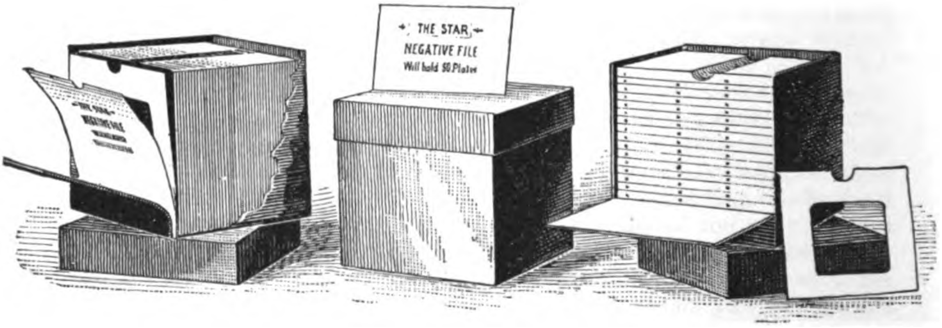

Fig. 540.—Star negative file.

Large films had better be kept in separate envelopes made for the purpose with a thin sheet of stiff cardboard and may then be placed in a port-folio, or filed between vertical partitions, or kept in a drawer. Their lightness and the fact that they cannot be broken makes films very much more convenient to preserve than glass plates.

FLUOROSCOPY AND RADIOGRAPHY OF SPECIAL PARTS OF THE BODY

The fluoroscope has a very definite field of usefulness; first, in determining the quality of the radiance, and second, in the examination of cases in which a glance tells the whole story. Time passes so rapidly when a patient is being examined and considered that the use of the fluoroscope may lead to a dangerous length of exposure. One case in point was communicated to me privately by an eminent physician in this city. A friend of his had some affection of the knee-joint for which a fluoroscopic examination was made and a consultation held, it being estimated afterward that the knee had been exposed to the *x*-ray for forty-five minutes. The result was a dermatitis followed by a painful and intractable ulcer with such an effect upon the system at large that to save the man's life and reason an amputation was performed above the knee. Another case was reported by an excellent radiologist, Guilleminot,[1] who had been in the habit of removing foreign bodies from the hand under fluoroscopic observation. For instance, he would roughly locate a needle by means of the fluoroscope, take the patient into daylight and make an incision, then in the dark again guide the forceps, by means of the fluoroscopic image, until the needle was felt and seized. In the case reported the needle could not be found, although two separate attempts were made four days apart. During these two séances the patient's hand and both the doctor's hands were actually exposed to the x-ray for about thirty-five minutes. The distance from the tube was 3 or 4 inches, the vacuum was low. Although he does not give the strength of current used, it must have been considerable to enable the needle to be seen. The patient's hand and both the surgeon's hands developed a very severe dermatitis with ulceration which took six months to heal completely and the skin was not absolutely sound at the end of a year. It does not follow that the fluoroscope should never be used, but it is certainly very dangerous in a case where the image has to be studied for an uncertain length of time.

THE HEAD

Radiographs of the *cranium* as distinguished from the face may be made on two different plans. One, which I designate as a *marginal picture,* is occasionally useful when the portion to be studied is a part of the skull or, at all events, is near the surface. In such a case the head is to be placed upon the photographic plate in such a position that the shadow of the portion of interest will be at the margin of the general image of the head. If, for instance, it is about the forehead, the sagittal suture, or the occiput, the plate would be placed at the side of the head; while for a marginal picture of the temporal region the patient would lie with the plate under the back of his head.

In the other, which I call the *direct radiograph* of the cranium, the portion of interest is brought as close to the plate as possible and its shadow usually falls at about the middle of the general image of the cranium. For a direct radiograph of a tumor of the brain the plate would commonly be at the side of the head. A marginal radiograph of the cranium should show both tables of the skull quite clearly.

Fractures of the skull sometimes show very well in the marginal view with the fluoroscope, as do also depressions or thinning of the skull from the pressure of cysts and tumors, but with the abnormal portion of the skull in the center of the image, the change is rarely visible with the fluoroscope. The radiograph, however, is extremely valuable. The current used for an induction-coil should be 18 to 25 amperes, and the tube should be 13 inches from the skin to the anticathode and should have a medium vacuum, resistance about 3 inches, and penetration No. 6 Benoist. A transformer, or an unfluctuating converter, would make the picture with 70 kilovolts and 30 to 50 milliamperes. The exposure with the coil would be from fifteen to sixty seconds and with the more powerful apparatus one-fourth to one second. In radiographing a case of fracture of the skull in profile the plate should be placed upon a pillow on the

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[1] Archives D'Electricite Medicale, Bordeaux, France, Dec. 10, 1904.

examining table beneath the patient's head, the tube being 15 inches above the plate. For a radiograph looking directly at the injured portion two methods are available. The tube may be at a distance of 20 inches from the plate, securing a picture of the entire head free from distortion, injured portion resting on the plate, vacuum medium high, resistance 4 inches, radiometer No. 8 Benoist; or the author's screen for soft rays may be used with a shield. It enables us to bring the anticathode within 10 inches of the plate without danger of dermatitis, and gives the structure of the portion of bone nearest the plate almost unobscured by the distal image. Of course, the whole head is not shown; the image would be distorted with the tube so close. This means that the tube is very near the skin, and a preliminary test should be made of the *x*-ray dosage at this distance and with the proposed strength of current so that the skin may not be exposed to more than a fraction of an erythema dose. And to make assurance doubly sure an intensifying screen may be used which will reduce the time of exposure to one-tenth.

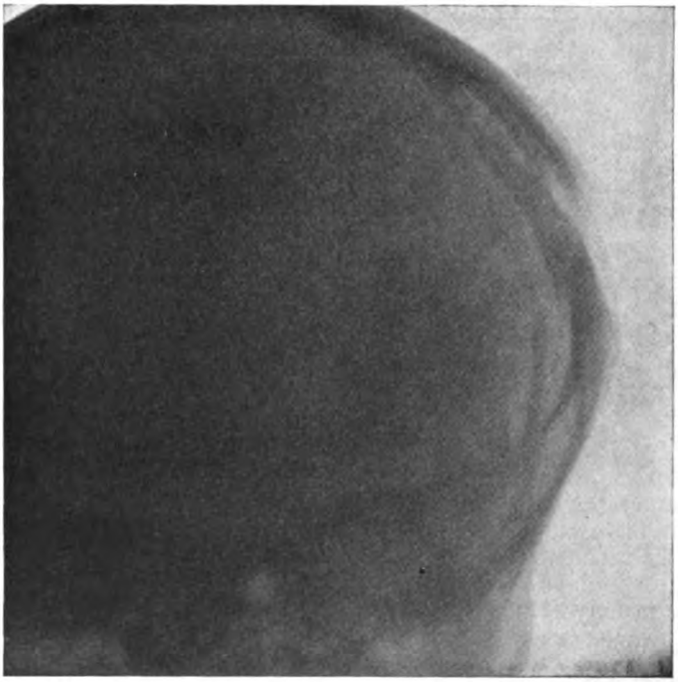

Fig. 541.—Marginal radiograph of depressed fracture of the skull, seven years after injury.

Fig. 541 is a radiograph of such a case. The patient, a boy of seven years of age, was beginning to lose his memory, possibly in consequence of an injury received when a baby. His father had thrown a saucer at the mother, but hit the baby's head, making a gutter-shaped depressed fracture which still shows in the radiograph.

Radiographs proved of value in cases of "Bursting fracture" of the skull, reported by Wight,[1] the profile as well as the direct view being successful.

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[1] New York Medical Journal, April 27, 1907.

Differential Diagnosis Between Hematoma of the Scalp, Hernia Cerebri, and Fracture of the Skull.—The author has several times successfully based this distinction upon the fluoroscopic appearance alone. The profile view of a hematoma shows the uniformly convex surface of the skull. The raised margin of the saucer-shaped depression is seen to be entirely transparent and superficial to the bone which takes no part in its formation. Turning the head a little to one side or the other does not show any area of translucency in the bone. A direct view with the fluoroscope, that is, with the affected portion of the head nearest the fluoroscent screen, is not as conclusive as a radiograph made in this position. The radiograph showing a profile view gives the same results exactly as the fluoroscopic examination.

A depressed fracture of the skull would be seen very easily with the fluoroscope in profile, but here again the radiograph would be necessary for a direct view. Making almost a profile radiograph, that is, with the head turned a little toward the plate, we will get an image showing irregularity and some translucency, which, however, is very much less than is the case in hernia cerebri, or in diseases characterized by the absence of bony tissue in a certain area.

The last mentioned disease, hernia cerebri, presents a notched outline when the skull is examined in profile by the x-ray; and in a semiprofile view a very distinct circumscribed area of translucency. The latter is also shown very well in a direct view, but requires a radiograph, The strength of current, quality and intensity of the ray, and distance from the plate are the same as in other direct and marginal pictures of the head.

Tumors of the Brain.—Fluoroscopic examination is not to be recommended for a tumor of the brain. There always appears to be a denser area in the part nearest the observer. Radiography of a brain tumor requires the same technic as in the profile radiograph of a fractured skull. Two pictures should be made, one with the plate behind and the tube directly in front at a distance of 20 inches from the plate, and the other from the same distance with the plate at the side of the head on which the tumor is supposed to be located. While many radiographs have been made which showed the presence of tumors of the brain, subsequently verified by operation, still such a radiograph is not sufficiently clear to be accepted as anything more than corroborative evidence. The radiographer is not the one to decide whether an operation is necessary or not.

The *ventricles of the brain* were shown to be full of air in a traumatic case radiographed by W. H. Luckett[1] (Figs. 542 and 543).

The diagnosis was confirmed by an autopsy.

***X*-ray Examinations for Foreign Bodies in the Cranial Cavity.**—The exact localization of a bullet or other foreign body will enable the surgeon to judge of the desirability of an operation for its removal.

Bullets or other foreign bodies in the brain are shown in a radiograph made with the plate in a stereoscopic holder upon the table and the most probable part of the head resting on it; the tube diametrically opposite. It will be better, however, to use the author's lateral plateholder as described on p. 896. This enables one to make a preliminary fluoroscopic examination and turn the patient's head into the position

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[1] Surg., Gynec., and Obst., August, 1913, 237.

at which the foreign body will be nearest the plate. It is very desirable to mark a small spot on the head with nitrate of silver just where the image of the foreign body is seen. This is done while looking through

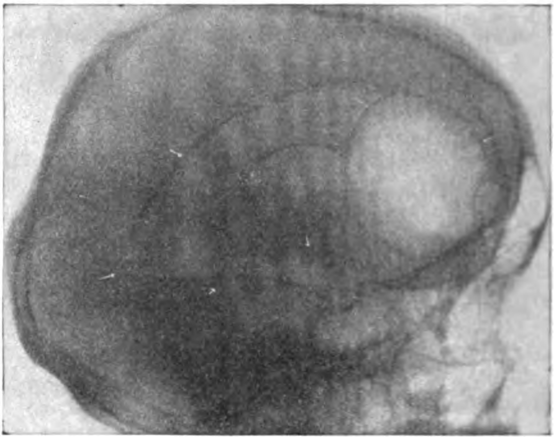

Fig. 542.—Air in the ventricles of the brain. Lateral view. The arrows outline the distended ventricles. The large round white shadow is the right anterior horn (W. H. Luckett).

the fluoroscope. A similar mark may be required in some cases at the opposite side of the head to indicate the direction of the tube. Then

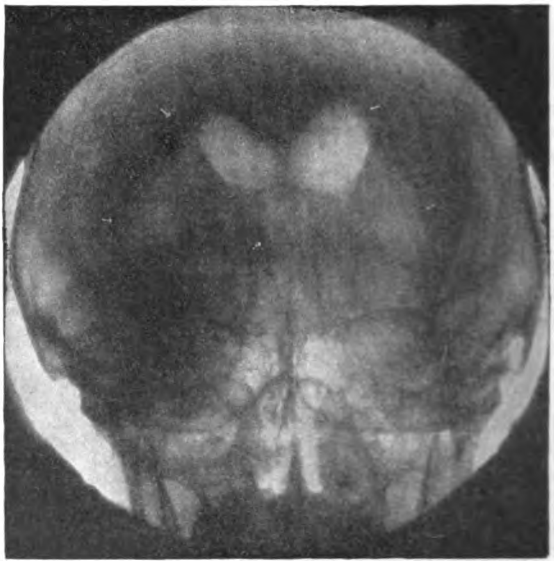

Fig. 543.—Air in the ventricles of the brain. Anteroposterior view. Two lateral ventricles distended with air. Small round white shadow just between and below is the third ventricle also distended with air. Arrows indicate the positions (W. H. Luckett

the plate in a stereoscopic holder is placed between the patient's head and the vertical board of the lateral plate-holder, and the radiograph is made.

Localization.—A single radiograph of a foreign body in the cranium does not indicate the exact depth at which the body is located. Clearness and apparently natural size of the image indicate proximity to the plate; while vagueness and enlargement indicate that the foreign body is at a distance.

In certain cases two separate radiographs may be made in directions almost at right angles with each other. The cranial landmarks shown in the radiographs may enable one to locate the foreign body at the intersection of two definite lines. It is always better, however, to mark both of these lines by two pairs of nitrate of silver stains applied under the guidance of the fluoroscope.

The two radiographs at a right angle are not practicable or desirable in some locations in which a foreign body may lie. In such a case stereoscopic radiography may be useful.

Stereoscopic Radiography of Foreign Bodies in the Cranium.—The stereoscopic plate-holder may be flat upon the table with the patient's head resting upon it and tube above; or the author's lateral plate-holder may hold the stereoscopic plate-holder in a vertical position while the patient lies with the proper part of the head in contact with the plate-holder, and with the tube diametrically opposite. One radiograph is made with the tube in a certain position and then the plate is removed from the plate-holder and another plate inserted in exactly the same position. The patient has held perfectly still during this change. The *x*-ray tube is then shifted 2½ inches to either side and another radiograph is made. A pair of such pictures examined with a stereoscope gives a combined image in which the perspective is shown. Quite an idea may be obtained as to the distance of the foreign body from the plate, but no exact measurement.

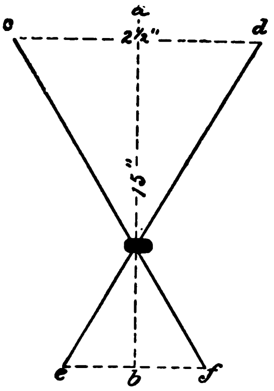

Fig. 544.—Localization of a foreign body in the head by triangulation.

Localization by Triangulation.—This is used in the same cases that are suitable for stereoscopic radiography and gives much more accurate results.

Two pictures are made with the head and the plates in the same position, by means of a stereoscopic plate-holder, but with the tube moved to either side for a distance of 2½ inches after the first picture. The tube being at a distance of 15 inches from the plate the distance that the image of the foreign body is shifted enables one to calculate by simple geometric rules its distance from the plate (Fig. 544). The position of the foreign body may be determined in this way to the fraction of an inch.

The details of a more exact method of localization by triangulation involves the use of cross wires marking exactly the same position on the two successive plates, and also a solid metal object fastened upon the head at a portion about as distant as the supposed position of the foreign body. This is more fully explained in the section upon the radiographic localization of foreign bodies in the orbit. McKenzie Davidson's localizer is also excellent for these cases.

In somes cases it is sufficient to use only one plate, making two separate exposures with the tube in two different positions. This produces two separate images of the foreign body on the same plate, but the rest of the picture is somewhat blurred. Such a radiograph (Fig. 545) was taken of an empty skull with the x-ray tube in two different positions. Two plates were used, but were in identical positions. If they are now superimposed, the brass springs and screws which hold the jaw in position show double images. The screw on the side nearest the plate casts two shadows which almost coincide, while the screw on the side of the skull opposite the plate casts two shadows which are at a considerable distance apart. A calculation based upon the distance between the two images, the distance from the plate to the tube, and the distance between the two different positions of the tube would give the distance from the plate to the screw.

Two cases of x-ray localization of bullets in the cranium and their successful removal were reported as early at 1899 by Lucas.[1]

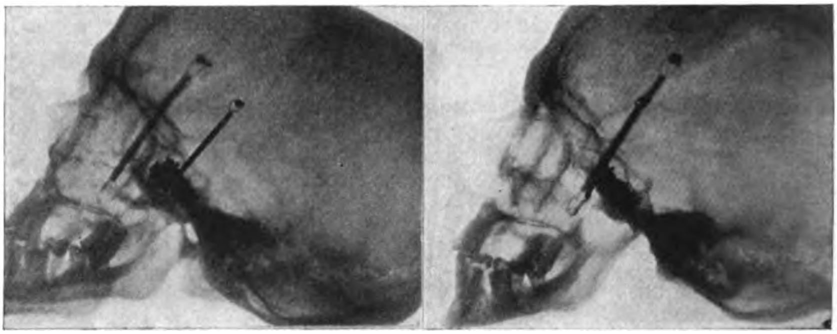

Fig. 545.—Stereoscopic radiograph of the sphenoidal sinus filled with lead shot.

An interesting skiagraph by W. A. C. Hammel was published by Gamble and Tiffany,[2] showing a *chisel* 4½ inches long which had been projected violently into a man's neck and had remained concealed in the tissues for sixty-nine days. The radiograph showed that the lower end of the chisel rested against if not in the body of the fifth cervical vertebra, while the upper end extended an inch above the level of the hard palate. It had evidently gone downward and backward through the upper jaw bone.

A case in which an x-ray examination would doubtless have saved life was one which came to the attention of the author, though not under his care, before the discovery of the x-ray. The patient had been struck on the head by a heavy piece of wood and sustained a scalp wound which healed promptly and the man seemed all right for some weeks, but then quite suddenly developed symptoms of brain abscess and died in a few days. It was found that a nail had been driven into the brain and had broken off flush with the outer surface of the skull.

One glance with the fluoroscope at the head in profile would have revealed the presence of this foreign body.

A similar case is reported by O'Hanlon, Coroner's physician in

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[1] Brit. Med. Jour., Oct. 21, 1899.

[2] Phila. Med. Jour., Jan. 6, 1900.

New York City, Jan. 21, 1905. The patient was treated at one of the hospitals for a scalp wound which healed promptly, but thereafter the man began to have epileptiform convulsions. A radiograph was made some months later which showed a bullet lodged beneath the anterior lobe of the right hemisphere of the brain. But the man had left that hospital before the plate was developed and during the entire eighteen months that he lived no one else suspected even the occurrence of a pistol wound. He died of an abscess of the brain and the Coroner's physician discovered the bullet. The bullet itself appears to have been innocuous, but a fragment of the bullet with a sharp bit of bone adherent to it set up the irritation which eventuated in abscess of the brain and death.

In a case reported by Weiser[1] radiographs showed a bullet lying in the cerebellum. There were marked symptoms at first, but the bullet was not removed and the patient became apparently perfectly well.

Foreign Bodies in the Orbit or the Eye.—These are usually of small size and the exactness with which they must be located makes its accomplishment by means of the fluoroscope alone require a dangerously long exposure.

Radiographic localization is based upon one of two general principles. By one method, not often used, an anteroposterior radiograph is taken upon a plate in front of the face, the tube being behind the head. Then a lateral radiograph is made upon a plate at the suspected side of the face with the tube at the other side. These two pictures enable us to locate the foreign body at the intersection of two lines. In such a delicate organ as the eye, small fractions of an inch count for a great deal. The general topography of the cranial and facial bones, as shown in the radiograph, does not afford sufficiently minute exactness for this purpose. Landmarks are required, such as bits of lead, which some operators have sewed fast at the upper and the lower border of the cornea. The patient must be instructed to look straight ahead during the exposure to the *x*-ray. The anteroposterior radiograph will show at what distance the foreign body lies from the vertical line passing through these two bits of lead, and the lateral radiograph at what distance behind the same plane. Both radiographs show the level of the foreign body.

It is a matter of saving the eye, and these bits of lead can be attached without any injury and without pain if cocain is used. This method is, therefore, perfectly proper if regarded as necessary.

A similar method is to fasten a bit of lead on the outside of the upper eyelid directly over the center of the pupil, the lid being kept closed by a bandage. The patient should be cautioned not to move the eyelid.

Still another plan is to have a lead ball held just in front of the middle of the cornea by a stem fastened to the plate-holder.

The patient may lie upon the table at first face down upon the plate and then with the affected side of the face resting upon the plate, or the author's lateral plate-holder may be used to hold the plate in a vertical position close to the patient's face. At first the patient lies on his side facing the plate; and later face up with the plate at the affected side.

The *x*-ray tube may be enveloped in a shield with a leather disk to

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[1] Boston Med. Surg. Journ., March 22, 1906.

arrest the soft rays, or Albers Schönberg's compression cylinder or similar apparatus may be used. The x-ray tube should not be entirely free.

The anteroposterior picture is made with the tube at the same distance and position and with the same strength and quality of ray as recommended for anteroposterior frontal sinus radiographs.

The lateral picture is much easier. The distance from the plate to the anticathode should be about 17 inches, the penetration about No. 6 Benoist, and the exposure about half a minute with an induction-coil or a fraction of a second with a transformer or an unfluctuating converter.

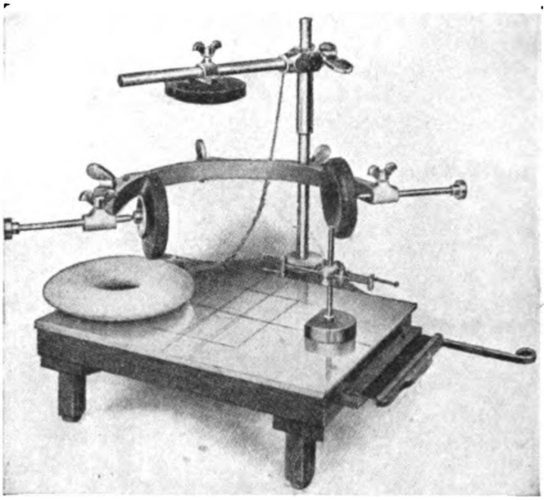

Fig. 546.—Localizer for foreign bodies in the eye and orbit. (Sweet method).

The head should be held perfectly still, sand-bags being used if necessary.

Anything as large as a shot would be easily located in this way, but smaller objects, like small splinters of steel or glass, might not be discoverable in the anteroposterior image.

Localization by Triangulation.—This is the only method which is applicable to all cases, even those in which it is necessary to decide whether a spicule of steel or glass is imbedded in the sclera or just outside or inside.

Sweet's apparatus (Fig. 546) or Bowen's or Dixon's may be used.

The principle is that two lateral pictures are taken with one or two bits of lead held in the same position close to the eye while the tube is moved laterally. The distance and direction of the foreign body from the one or two bits of lead and from two cross wires in the two separate pictures form the basis of a geometric calculation from which the exact position of the foreign body is found. Charts printed by Meyrowitz, of New York, give the result by a graphic process without algebraic formulas.

One of the bits of lead is held close to the eye and directly in front of the middle of the cornea; if the other is used, it points to the outer border of the eyeball.

Sweet's method is to have the patient lie face up with the head secured in an apparatus which includes also the holder for the bits of metal, and for the x-ray tube and the photographic plate. It is not desirable for the patient to sit up and hold the plate against the side of the face. It would be difficult for him to hold still enough for the first picture and still more so when it came to removing the first plate and substituting the second.

Dixon's Apparatus.[1]—This forms a lateral plate-holder for one 4×5-inch plate. It conforms more or less to the shape of the head, and is provided with a clamp for holding the head in position. The patient lies face up while the plate is held near the affected side of the face and the tube is at the opposite side. The bit of lead is connected with a head band by which it is held in position a very few millimeters in front of the middle of the cornea.

Bowen's Arrangement.[2]—This consists in having the patient lie with the affected side of the face resting upon a horizontal plate, with the tube over the opposite side of the face, and the two bits of lead fastened to a stem whose heavy base rests upon the plate.

In all these methods of localization by triangulation the first radiograph may be made with the tube in a line with the one or two bits of lead, or 1½ inches to either side of that line. The second one is made with the tube moved 3 inches laterally, a little above the line of the one or two bits of lead.

A stereoscopic plate-holder is convenient because it enables one to remove the first plate and insert the second without the patient moving. It is not used because of any necessity that the two plates should be placed in absolutely the same position, so that the picture would come on exactly the same part of each plate, as in stereoscopic radiography. All that is required for the present purpose is that the successive plates shall lie in the same plane. Some operators prefer to take both pictures upon different parts of the same plate to prevent their ever becoming separated or mixed up with radiographs of some other case. Heavy lead is placed over one part of the plate while the first picture is made; then the position of the plate is changed and the lead placed over the first part of the plate while the second picture is made.[3]

The eye should be fixed in position, and if it is open this is best accomplished by placing a bright object at the proper position for the patient to look at, or he may look at the reflection of his own eye in a small mirror. Another way is to place the center bit of lead against the eyelid over the middle of the cornea with the eye closed. There is then very little probability of the eye moving.

The tube may be out in the open air or enveloped in a localizing shield or a compression cylinder may be used. The latter would not be for compressing or even for immobilizing the head, but simply for its effect in cutting out secondary rays. The author's preference is for a localizing shield with a sole-leather disk to arrest the soft rays.

The radiograph is not a difficult one to make. The distance from anticathode to plate should be about 18 inches; the penetration No. 6

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[1] Annual report of the N. Y. Eye and Ear Infirmary, 1906.

[2] American Quarterly of Röntgenology, vol. 1, No. 4, July, 1907.

[3] Hickey, American Quarterly of Röntgenology, July, 1907.

Benoist for metallic objects, or No. 4 Benoist for bits of glass, and the exposure from fifteen seconds to a minute.

Details of Localization by Dixon's Apparatus.—The patient lies face up on the table with head clamped to the lateral plate-holder after the head has been squared by a special apparatus. This is to make the sagittal plane of the head parallel with that of the photographic plate (Figs. 548 and 549).

It has been found that straps are not required to immobilize the patient's head. This object is better accomplished by an aluminum bar which is passed across for the patient to bite on and is firmly fastened in place. A small sand-bag makes an adjustable cushion for the head.

Fig. 547.—Radiograph by Dixon with his apparatus for localizing foreign bodies in the eye.

The tube is placed with its anticathode at a measured distance of just 50 cm. from the plate and is normal to the plate at the intersection of the cross wires. This direction is obtained by sighting from a brass notch behind the plate and through the intersection of the wires.

Fixation of the eye is obtained by having the patient look, chiefly with the uninjured eye, of course, at a small wooden ball suspended about 40 inches above the exact center of the cornea of the injured eye. This centering has been obtained by lowering the wooden ball to within a short distance of the injured eye and then adjusting the cross bar, from which it is suspended, until the ball is directly over the center of the cornea, and then pulling it up into position.

The marker is a drop of solder on the end of a brass wire, which is fastened to an adjustable rod attached to the patient's head by a band just like a forehead mirror for laryngoscopic or aural examinations. It is fastened directly in front of the middle of the cornea and at a measured distance, 2 or 3 mm., from it.

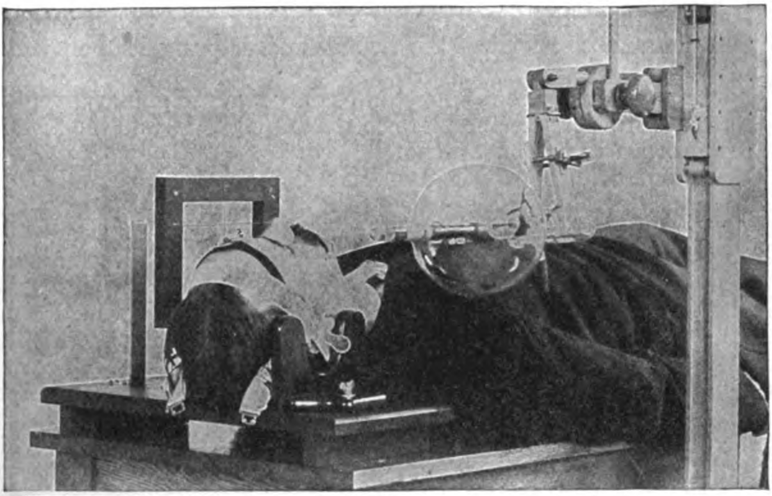

Fig. 548.—Dixon's method of localizing foreign bodies in the eye. Safety to operator and patient requires that the *x*-ray tube should be enclosed in a protective shield.

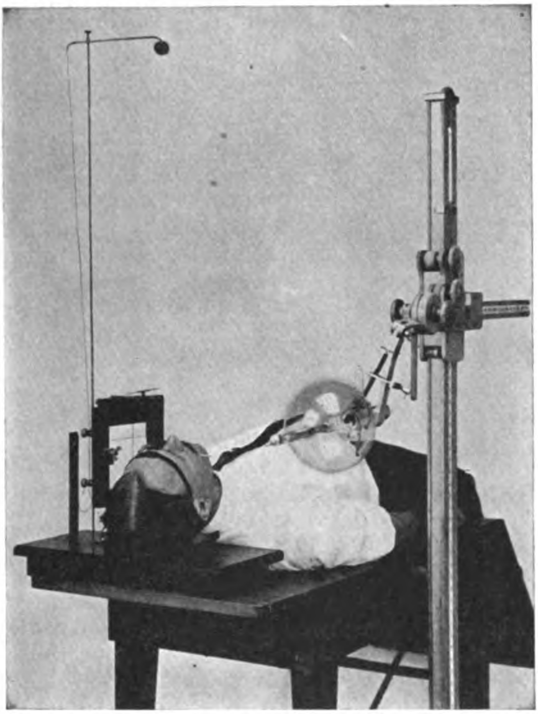

Fig. 549.—Showing fixation of the eye in Dixon's method of localizing foreign bodies in the eye. A localizing shield should be used.

Before making the first exposure the *x*-ray tube is lowered vertically 3 cm. This means backward with reference to the patient who is lying face up.

After the first exposure the tube is raised 6 cm. or to a point 3 cm. above its normal position and the second exposure is made upon another plate.

The calculation of the result requires only two preliminary measurements: the distance from the plate to the anticathode, and the distance from the cornea to the bit of lead.

Quotations from a case in Dr. Dixon's monograph show how the localization is made. The distance from the anticathode to the plate was 51.5 cm. and that from the cornea to the bit of lead, 3 mm.

Take a piece of drawing paper and draw a line, *a*, right across it, which indicates the normal line at the intersection of the cross wires. A line marked *b*, at a right angle to *a*, and at a distance, in this particular case, of 51.5 cm., will indicate the vertical line along which the *x*-ray tube is moved. A line, *c*, also at a right angle to this, near one end, will represent the plane of both the first and second photographic plates.

The line *a* on the photographic plate represents the cross wire which is parallel with the length of the patient's body, and the line *b* the wire at right angles with it.

A measurement is made on the first plate of the distance from the line *a* to the point of the lead indicator. This distance is measured off on the diagram from the line *a* along the line *b*, and the point reached is marked *o*.

Another measurement is made on the first plate of the distance of the foreign body from the line *a* and the result of this is marked on the diagram as the point *x*.

Similar measurements on the second photographic plate give the points *o* and *x* on the diagram.

Now mark the position of the tube at the time of the first exposure at a point *Ex. 1* on the line *b* at a distance of 3 cm. from the line *a*. Mark also another point *Ex. 2*, indicating the position of the tube during the second exposure.

Draw lines on the diagram from *Ex. 1* to x' and o'; and from *Ex. 2* to *o* and *x*. The lines to x' and *x* will be found to have crossed in space at a point which is marked x''; and the lines to o' and *o* cross at o''.

The direction and distance of the point x'' from a line drawn through o'' parallel with *c* show whether the foreign body is toward the photographic plate *c* or toward the median line of the head, and at what distance it lies from the vertical axis of the eye.

Only one factor in the localization of the foreign body remains to be determined, and that is the distance above or below the horizontal axis of the eye. The distance from the cross wire *b* to the indicator should be the same on the two plates if the tube and head are properly placed.

These two distances are measured upon the line *c* in the diagram.

Lines are drawn from the two points, x^3 and o^3, thus found to the middle point of the line *b*. The intersection of the line passing to x^3 with the line drawn through x'', parallel with the line *c*, shows the location of the foreign body upon a horizontal plane, while the intersection of a line drawn to o''' with a line drawn through o'' and parallel with the line *c*, shows the position of the indicator on the same plane.

Plotting these measurements upon the chart, in this particular case, we measure off 10 millimeters back from the center of the cornea, and

8 millimeters below the horizontal plane, and 6 millimeters to the temporal side, and thus indicate the point of location of the foreign body in the eye. The method of location by triangulation is due partly to McKenzie Davidson and partly to Sweet, Fox, Hulen, Dixon, and Bowen.

In making all the different measurements one should be careful to use the same part of the image of the foreign body, if the latter is larger than a mere dot. It is easy to see how errors of a distance equal to the diameter of the foreign body might result if the same portion were not selected for all the different measurements.

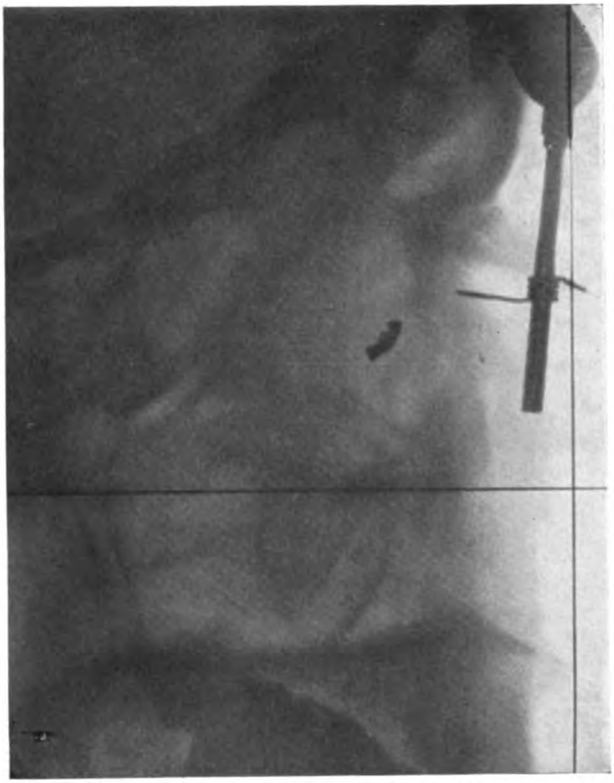

Fig. 550.—Radiograph by Dr. Dixon localizing foreign body in the eye.

This foreign body (Figs. 550 and 551) was so large that separate measurements were made to locate its different extremities.

The *anterior extremity* was	
back from center of cornea	4.5 mm.
to nasal side of center of cornea	1 "
The *posterior extremity* was	
back from center of cornea	9.5 "
to temporal side of center of cornea	3 "
The *superior extremity* was	
below center of cornea	4 "
The *inferior extremity* was	
below center of cornea	9.5 "

The foreign body measured 2×5×9 mm. and weighed 0.4719 grams.

A radiographic examination should be made in every case of injury to the eye by a foreign body when there is reduced visual acuity, whether there is a distinct history of possible penetration by a foreign body or not.

The foreign body may possibly be so small that its shadow escapes detection, but this is unlikely in an excellent radiograph.

Allowance must sometimes be made for myopia or hypermetropia in calculating the position of the foreign body. The variation from the normal diameters of the eye-ball may have to be considered.

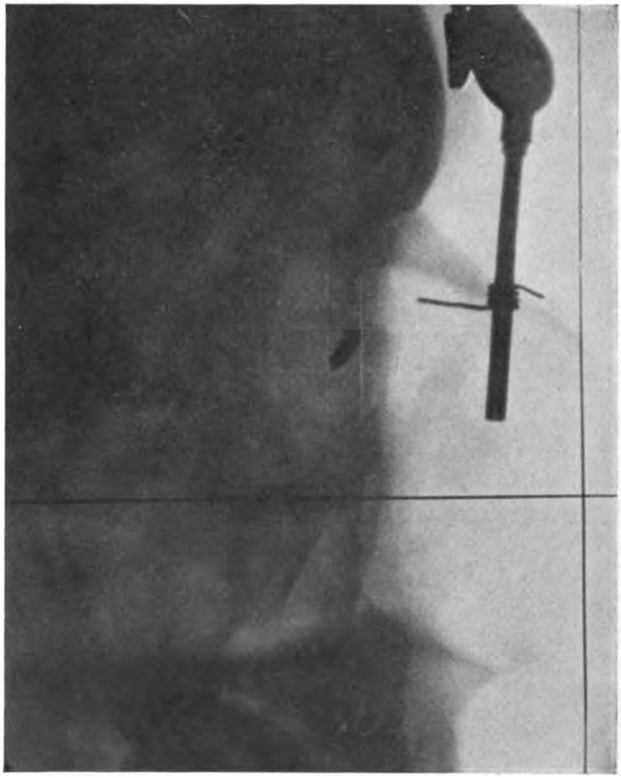

Fig. 551.—Second radiograph in the localization of the foreign body in the eye (see Fig. 550).

De Schweinitz[1] has observed slight variations which make it difficult to say whether a bird-shot is either at or immediately outside or inside the sclera.

The anteroposterior diameter of a normal eye varies from 20 to 25 millimeters, and in one case in which Dixon located the shot just outside the sclera Dr. Marple found it to be just inside. The man measured 6 feet 2 inches in height and had an eye 26 millimeters in diameter. If this fact had been taken into consideration the location would probably have been correct.

Stilling states that variation in the diameter of the eye-ball is independent of errors of refraction and that a myopic eye of 4 D. may be actually shorter than a hyperopic eye.

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[1] Journal Am. Med. Assoc., Aug. 11, 1906, p. 422.

The *x*-ray may be used to ascertain whether a shot which at first has been lodged in the vitreous, or elsewhere, has become loosened and fallen onto the ciliary body. Such a change in position might be followed by iridocyclitis. Cases have been reported by Marple[1] in which the *x*-ray has shown that there has been a double perforation of the eye-ball by a shot, the latter having gone completely through the eye-ball and being lodged in the tissue outside. The diagram reproduced in Fig. 552 represents Dixon's chart for use in these cases.

Radiography of the Ear and the Mastoid Cells.—The classical picture of this region is made in the method elaborated by Lange.[2] The direction of the ray is from the *x*-ray tube, placed on the opposite side at a point 25° above the horizontal line between the auditory meati and 20° behind that line. The plate is pressed against the affected side of the head, the ear being bent forward. This gives a picture of one mastoid region and includes the lateral sinus. Another symmetric radiograph should be made of the opposite side for comparison.

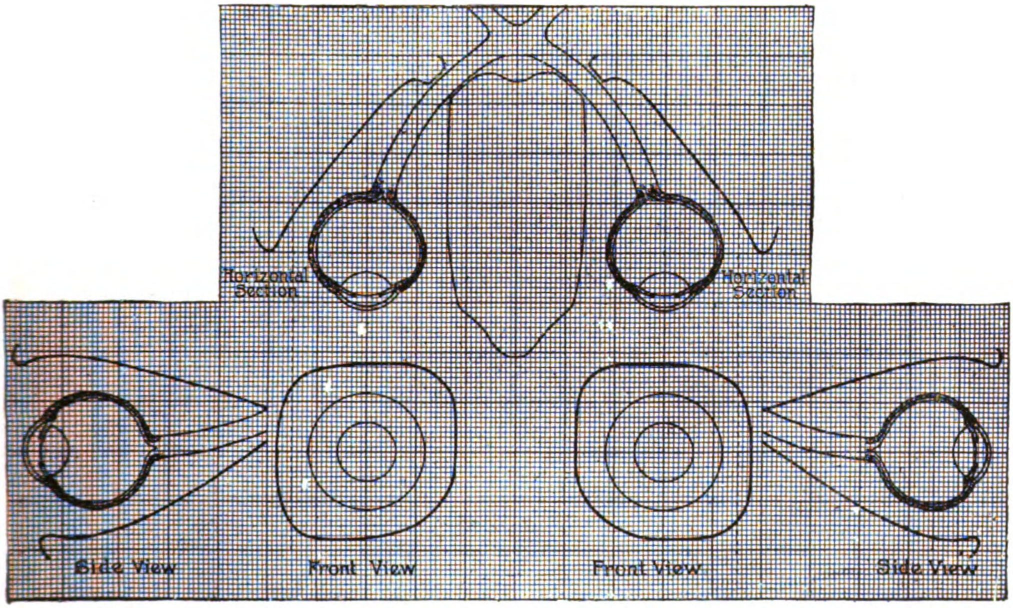

Fig. 552.—Weeks and Dixon's modification of Sweet's chart for plotting location of foreign bodies in the eye and orbit.

A position employed by Wm. H. Stewart[3] is with the patient lying face up and with a somewhat raised platform under the head so that the occiput rests upon the plate. The tube is placed above the head, but about 15° back. This gives a simultaneous view of both mastoid regions down to the tip of the mastoid processes. The author suggested in the discussion that Stewart's position could be used to obtain better

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[1] Journal Am. Med. Assoc., Aug. 11, 1906, p. 421.

[2] Meeting of American Röntgen Ray Society, 1909; Fortschr. Roent. Strahlen, July 8, 1910, p. 208.

[3] Otological Section, New York Academy of Medicine, May 12, 1913.

single pictures by displacing the tube first to one side and then to the other for the second plate.

The mastoid cells of both sides show very well in an anteroposterior radiograph made with the tube behind and in the median line while the plate is in front. The greater length of the plate should be transverse. The anticathode of the tube should be on a continuation of the line from the external auditory meatus to the tip of the nose, so as to make the shadow of the malar bone fall above that of the mastoid cells. The picture is a difficult one to make, and is made as follows: Penetration, 7 Benoist; distance from plate to anticathode, 19 inches; exposure about sixty seconds with an induction-coil or about one second with a transformer or an unfluctuating converter. An intensifying screen will reduce the time of exposure to one-tenth, and if several pictures are to be made the element of x-ray dosage becomes important. A diaphragm and a sole-leather screen are desirable. The diaphragm should be of non-conducting material, so that it may be in immediate contact with the x-ray tube and give a wide angle of radiation.

The mastoid cells and the middle and internal ear are shown very well in a radiograph made with the plate at the affected side of the head and the tube at the opposite side in the continuation of a line passing through the head an inch above both external auditory meati.

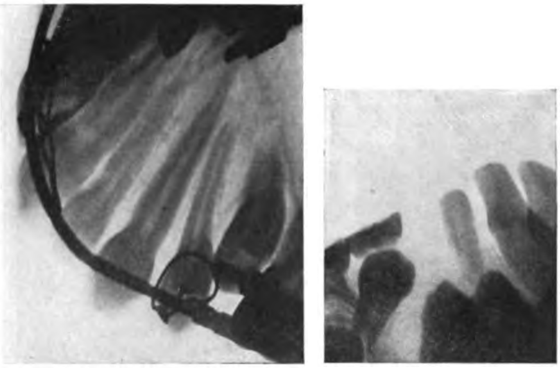
The plate is to be studied by transmitted light in a negative examining box. Air cells appear dark, which is changed to light if the cells are full of pus.

The picture is not very difficult, although the plate may be a little thin or faint.

X-ray Diagnosis of Tumors of the Pituitary Body.—This is a disease which often causes absorption of the posterior clinoid processes and enlargement of the sella turcica. A. J. Giordani has made a number of successful diagnoses of this condition from radiographs.

The radiograph should be taken laterally, with the normal ray passing directly through both external auditory meati and with the anticathode about 19 inches from the plate. The x-ray should be about No. 7 Benoist, and the exposure will vary from forty seconds with an induction-coil to a fraction of a second with a transformer or an unfluctuating converter. A diaphragm or cylinder improves the definition.

Examination of the Teeth and Maxillæ.—One of the most important applications of the x-ray is in dentistry. The greater density of the teeth makes them show very well in contrast with the less dense substance of the jaw, and with a certain quality of ray the tooth itself is transparent and its pulp-cavity and root-canals may be studied and even pulp-stones may be discovered. One of the conditions studied is the existence and position of unerupted teeth, or, what is equally important, the fact that the germ of the missing tooth is absent altogether (Figs. 553–557). Another is the extent to which softening and decay have taken place in a tooth. Fig. 558 shows an upper central incisor in which a cavity at a considerable distance above the gum-line was discovered and filled by Dr. Chas. C. Allen, of Brooklyn. A couple of years later he sent the patient to me suffering from indefinite slight sensitiveness in the same tooth. The picture showed an area of softening extending far beyond the limits of the filling, and indicating probably the destruction of the nerve. Acting on my advice, Dr. Allen pressed the gum far enough back to get at this part of the tooth, found very little



A *B*

Fig. 553.—*A*, Unerupted upper bicuspid tooth. Apparatus making a space for it; *B*, portion of lower jaw, showing presence of unerupted permanent teeth in a case in which all the temporary teeth were persistent at the age of twenty years.

Fig. 554.—Unerupted upper central incisor. The tooth itself bent and rotated.

Fig. 555.—Persistent temporary lower molar with unerupted bicuspid.

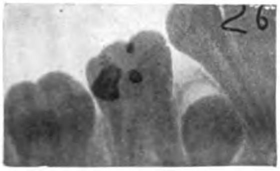


Fig. 556.—Unerupted lower bicuspid. Faulty technic, since the radiograph does not show the area beyond the roots.

Fig. 557.—Persistent temporary lower molar. Apparatus for providing space for the bicuspid. Radiograph shows the latter is absent.

Fig. 558.—Caries of the root of upper central incisor. Black masses are fillings; several being at the proximal angles (where two adjacent teeth are in contact).

Fig. 559.—Extensive caries of the body and root of upper central incisor. This had not been suspected.

of the nerve and removed that, excavated, and filled a very large cavity in time to save the tooth from breaking off.

The condition of root-fillings and pivot teeth is easily determined (Figs. 560–565).

In some cases an unerupted tooth is the cause of anxiety simply as to the proper regulation of the teeth to accommodate it when it comes. In other cases the unerupted tooth is lying in a faulty position and causing harm in that way. Fig. 566 (young lady of seventeen, patient of Dr. J. S. Hasbrouck) shows an unerupted wisdom tooth growing in a direction almost at a right angle to the molar tooth in front of it, and causing the sudden appearance of very severe pain, which had continued without interruption for three days. The cause of the trouble was suspected, but the fact that the lower canine tooth on the same side

Fig. 560.—Absorption of alveolus and small area of denudation at apex of root. Fistula and pain. Root-fillings excellent.

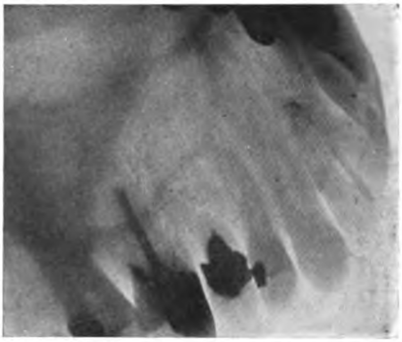


Fig. 561.—Normal antrum. First molar has excellent pivot tooth. Second bicuspid root shows marked absorption and a porcelain crown whose pivot does not extend far into the root canal.

Fig. 562.—Crown and bridge work. Pivot perforates the root of lateral incisor. Large area of necrosis.

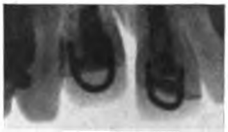


Fig. 563.—Pivot teeth. One upper incisor has retracted. This radiograph is defective in not extending beyond the roots. A better one showed absorption of the root and alveolus.

had not erupted made the *x*-ray examination indispensable. A glance at the jaw with the author's dental fluoroscope showed the faulty direction of the wisdom tooth and the entire absence of the germ of the missing canine, and this was confirmed by the radiograph.

Fig. 564.—Pivot tooth a little displaced and root canal not filled to its apex. Chronic irritation.

Fig. 565.—Excellent root-filling in first upper molar.

In a young girl (a patient of Dr. Chas. O. Kimball) the left upper lateral incisor had begun to be everted and also rotated on its axis. A radiograph showed this to be due to the faulty position of the unerupted canine, which as it developed was driving directly against the root of the incisor.

The Author's Dental Fluoroscope.—All the above conditions are easily seen with the author's fluoroscope (Fig. 567), published in the International Dental Journal, July, 1904. This is shaped somewhat like a dental mirror or a laryngoscope, but instead of a reflecting has a fluoroscopic surface on both sides, so that either the side toward or away from the *x*-ray may be looked at. It is placed inside the mouth, and the room being darkened, the *x*-ray tube is placed near the side of the face. The image of the teeth and roots and even of the structure of the jaw ½ inch beyond the apex of the roots shows very well. The tube should be of rather low vacuum, resistance 2 inches and radiometer 4; the current much less than for a radiograph, the anticathode 10 inches from the face, and the exposure only a very few seconds. For instance, the presence and position of the unerupted tooth may be determined at a glance, and this is entirely safe and may suffice for the whole examination or may serve as a guide to taking the radiograph from the most advantageous point of view. But a prolonged study of

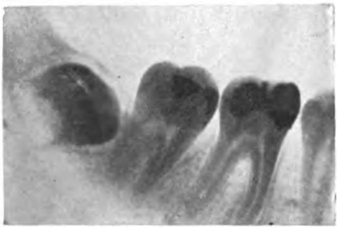


Fig. 566.—Impacted lower wisdom tooth.

the fluoroscopic image is as dangerous here as elsewhere. The study of detail should always be from the radiograph.

The Author's Magnifying Fluoroscope (Fig. 568).—This is a small trumpet-shaped metallic apparatus, about 4 inches long, closed at the large extremity by a fluoroscent screen with its coated surface inside. The smaller extremity has a flaring rim, which fits closely over one of the observer's eyes when in use, so as to exclude every particle of light. There is a magnifying lens in this end, which can be moved back and forth so as to focus the vision of the observer accurately upon the fluorescent screen, just as a jeweler's lens does upon his work. This fluoroscope is held close up against any part to be examined, and enables one to see details which are quite undiscoverable in the ordinary large fluoroscope.

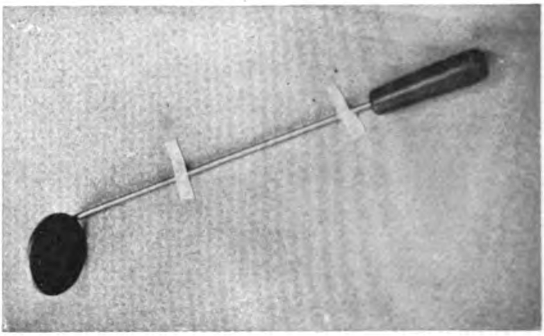


Fig. 567.—Tousey's dental fluoroscope. Its use is extremely dangerous to the operator and has been abandoned by the author.

It may be used with advantage in dental fluoroscopy, applied to the outside of the affected side of the face while the tube is at the opposite side. The lateral aspect of the upper jaw is accessible in this way for the study of the antrum, the alveolar process and alveoli, and the teeth. The latter are seen best with the tube at a lower level, so as to shine under the opposite teeth and then through the roof of the mouth on the affected side.

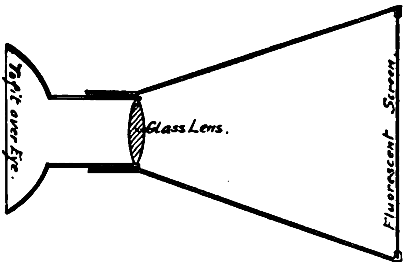


Fig. 568.—Tousey's magnifying fluoroscope. The use of this has been abandoned as too dangerous to the operator.

A single glance at the fluoroscope will show that the vacuum should be medium or low. With a fairly high degree of vacuum the roots of the teeth present hardly any contrast with the structure of the jaw. Quite a fair degree of intensity is required. The operator's face is necessarily so near the *x*-ray tube in making this examination that reasonable precautions must be taken to prevent injury. The chief one will be the use of the shield with a sole-leather disk, limiting the *x*-ray to a small area and arresting the soft rays, which are the ones likely to affect the operator's face. The use of lead-glass spectacles is desirable to protect the eyes. The hand should be protected by gloves opaque to the *x*-ray. Even with all these precautions, the examination subjects the operator to too much exposure to the *x*-ray to render it desirable as a routine method. The presence of a "nasal" tooth, which might escape observation by ordinary radiographic methods of study of the teeth, will be detected at once by this method. It is similar in the results yielded to the ordinary lateral radiograph of the whole face upon a plate placed at the affected side.

Dental fluoroscopy is chiefly useful in detecting the presence and position of unerupted teeth. It is not so useful as radiography for the study of structural details and is exceedingly dangerous to the operator.

Salvini[1] described a lens fluoroscope resembling the author's magnifying fluoroscope.

Dental Radiography.—For most cases the picture is produced upon a film, plate, or sensitized paper placed inside the mouth and closely applied to the inner surface of the teeth and gums. The *x*-ray tube is placed at a distance of about 13 inches from the anticathode to the face. It is of very great advantage to have the tube surrounded by a localizing shield affording the operator almost complete protection, and shielding all parts of the patient except about the mouth. The operator making many such pictures, and sometimes having to hold the film in position, would run a serious risk without some such shield, while the patient is not affected in any way by the fraction of a minute's exposure to a moderate radiance. One of the most important facts in regard to the *x*-ray is the cumulative nature of its effect on the tissues, and this has been productive of many serious accidents to operators and experimenters. Considerable latitude in the degree of vacuum is permissible. The resistance may be all the way from 2 to 9 inches, but where the root-canals are to be studied we would not use the lowest degree of vacuum. A 12-inch induction-coil is quite satisfactory. With more powerful coils the exposure may be five seconds, and with weaker coils forty seconds. The use of a transformer or of an unfluctuating generator reduces the exposure to about one-fourth second. The film for which these are the proper exposure is the Eastman positive cinematograph film, made by the Eastman Kodak Company of Rochester and London. It is many times slower than the ordinary kodak film. The exposure for the latter would be correspondingly shorter, but the picture produced is not so good. Eastman *x*-ray film, put on the market in 1912, is excellent and about three times as rapid as the positive cinematograph film, but does not give quite the same detail, and is usually a complete failure in midsummer heat. Slips of bromid paper require an exposure of fifty seconds with a 12-inch coil, and may be developed in any dimly lighted room. The finished picture may be made and pasted on a card within five minutes after the patient comes into the office. The author made a radiograph by this process at a demonstration before the First District Dental Society of New York State, December 14, 1904. The bromid

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[1] Proceedings Acad. Med. Chir. Perugia, Feb. 8, 1896.

paper is excellent for everything except fine details, and for these a film or a print made from a film is much better.

The films are cut into pieces, measuring about $1\frac{1}{4}$ by $1\frac{5}{8}$ inches, and usually two of these are wrapped together in black paper, and an outside wrapping of paraffin paper or the thinnest rubber-dam is applied just before placing the little package in the patient's mouth. The kodak company sell little packages containing two films of the correct size for a tooth picture already put up in a light-proof envelope. Two thin sheets of rubber, called palate rubber, may have their cloth covering stripped off and the adhesive surfaces fastened to the front and back of the film-pocket and their edges pressed together all around. The excess is trimmed away with the scissors not too close to the paper. Fig. 569 shows a convenient holder for dental films, by means of which they may be suspended in deep vessels containing the developing and fixing solutions and subsequently hung up to dry.

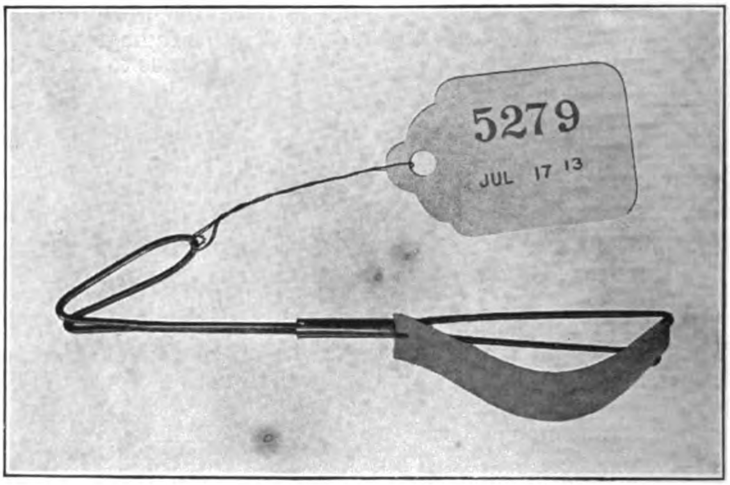

Fig. 569.—Satterlee's dental film-carrier.

Radiography of the Upper Teeth.—The upper teeth are not easy to radiograph correctly. Owing to the flatness of the roof of the mouth it is impossible to place the film in a plane parallel with the long axis of the teeth. The film is held close against the roof of the mouth, and the inside of the gums and the head must be tipped toward the *x*-ray tube (Fig. 540). If the proper angle between the surface of the film and the direction of the *x*-ray is not secured the image of the teeth shows them elongated (like shadows about sunset) or else foreshortened.

The *x*-ray tube is placed so that its anticathode is at a distance of about 10 inches from the sensitized film, and at such a distance above the level of the teeth that the image of the teeth upon the film will be as near as possible the same length as the teeth themselves. If it were possible to have the film placed in contact with the whole length of the teeth and their roots, it would make little difference at exactly what angle the tube was placed, but as the roof of the mouth slopes away from the roots of the teeth the film is not placed in contact with the roots or even exactly parallel with the long axis of the teeth. Some little study, therefore, is needed to make the image an accurate representation of the size of the tooth. An angle of 22 degrees will be found, in a rough approximation, to be the correct angle where the film is pressed against the teeth, gums, and roof of the mouth. The author has devised certain little film-carriers which can be held in the mouth in a vertical position, the film then being parallel with the long axis of the teeth. The tube would have to be a little above the horizontal level of the teeth in order that the image of the teeth should fall upon the film, but it will be readily understood that the image would be the natural length.

Radiography of the Teeth Upon a Horizontal Film.—A very good picture of the teeth of the anterior two-thirds of the upper jaw and of the anterior part of the antrum can be made by placing the film horizontally in the mouth and closing the lips and teeth upon it. For a picture of this character the position of the tube has to be decidedly higher than when the film is more nearly parallel with the axes of the teeth. An angle of 45 degrees will be found about right. The image of any particular tooth is best produced when the tube is directly opposite that tooth, so that the *x*-ray shines through the space between that tooth and the adjacent ones and makes a clear shadow of the tooth in question without overlapping part of the adjacent teeth. Two or three teeth are shown very well in such a picture, while the natural curve of the jaw results in simply a confused mass for the teeth beyond. The apex of the root of any tooth is at a somewhat greater distance from the film than the crown of the tooth, and consequently its shadow is a little enlarged and a little less distinct than that of the crown. The enlargement, however, is not sufficient to interfere with the result. The lack of dis-

Fig. 570.—Radiography of the upper teeth upon a small film held against the teeth and the roof of the mouth. Ripperger shield.

tinctness is more noticeable when the picture is of rather poor quality than when it is absolutely first class. A ray which will give a really good image of the tooth through the maxillary bone loses very little of its distinctness in consequence of a slight increase in distance between the object and the film. To obtain the best possible definition the author always uses a small diaphragm in contact with the *x*-ray tube, and makes certain that the small picture shall include the proper area by the use of a cylinder. The latter is not employed for compression or as a diaphragm, but simply as an indication of the direction of the rays.

Fig. 571.—Radiography of the upper incisor teeth upon a horizontal film.

Two films, 2 x 2½ inches, may be simply wrapped in black paper and paraffin paper or sheet rubber and held horizontally in the mouth by the patient. Such a picture requires a somewhat longer exposure than a picture taken upon a film held close to the inner surface of the teeth, the difference in time being that, if the latter picture requires ten seconds, the former should be given fifteen seconds' exposure. These are average exposures with an induction-coil, and are reduced to one-sixth and one-fourth second with a transformer or an unfluctuating current generator. The patient's head does not require to be fastened, although he should be cautioned not to move during the exposure. He may be seated in an ordinary chair.

Fig. 572.

Fig. 573.

Fig. 574.

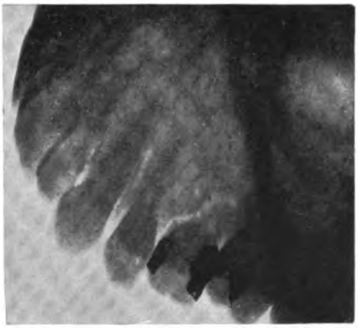

Fig. 575.

Fig. 576.

Fig. 577.

Figs. 572–577.—Radiographs made with the author's horizontal film-carrier. They all show the presence of unerupted teeth except Fig. 574, which shows absorption of the first upper molar root.

The usefulness of this method is greatest in the upper jaw, and especially in cases of suspected unerupted teeth and a large cyst or abscess cavity, which sometimes forms in the upper jaw. Taking considerable pains to have the film held as far back as possible in the mouth one may get a very fair picture of the antrum, but the roots of the molar teeth are apt to be somewhat indistinctly represented and not to be shown in exactly their normal relation or length. The last upper molar can hardly be studied in this way at all. Figs. 572 to 577 are radiographs made by this method, and show different parts of the upper and lower jaws. For the lower jaw the position of the tube is at a lower level than the face, and the chin rests in the orifice of the localizing cylinder, which is at an angle of about 45 degrees.

In all dental radiography the anticathode should be at least 13 inches from the skin to get the best results. The author felt at first that it was sometimes necessary for the operator to hold the film in position by placing his forefinger inside the patient's mouth. The finger itself was supposed to be protected by the fact that the ray has to shine through the patient's face first, but the rest of the hand is apt to be directly exposed to the ray. The protective gloves, in which some such substance as barium or lead oxid render them opaque to the *x*-ray, were used, but the tip of the forefinger of each one, and possibly the thumb, were cut away. This may be done in such a way as to leave the dorsum of the thumb and forefinger protected by the glove while the palmar surface is free. A better way in cases where it is practicable is to hold one edge of the film-packet in a pair of forceps, and in that way hold it in proper position inside of the patient's mouth. This will enable the operator to use gloves which have not had the fingers cut away, and also to have his hands beyond the range of the opening of the localizing shield. It will be difficult for the operator to hold the film absolutely still for the necessary length of time, and this difficulty is added to in some cases by involuntary motions on the part of the patient. The only place where the author has found this method at all easy is for the lower molar and bicuspid teeth. It is better and safer for the patient to hold the forceps after gently closing the mouth.

Fig. 578.—Tousey's vertical film-carrier.

The Author's Hands Injured by Dental Radiography.—The practice of holding the films in position proved exceedingly dangerous to the operator, who has to do it many hundred times, and left the author with incurable keratoses of the fingers, which if a little worse might have developed into epithelioma. A little instruction will enable any patient to hold the film himself and so protect the operator from the danger of frequent exposures.

Little film-carriers (Figs. 578 and 579) have been devised by the author for holding the film in this position by the patient simply closing his mouth upon them. One of these consists of a thin aluminum case which, when closed, is nearly water-proof and entirely light-proof. It takes two films about 1×1⅛ inches in size, and without any paper or other wrapping. These must be put in the film-carrier in the dark, of course. There is a sort of flange soldered to this which the patient holds between his teeth, while the part containing the films is thereby held in position. These vary somewhat in form, according to whether they are for the upper or lower jaw, and as to whether they are for front or back teeth. To prevent any possibility of a patient swallowing such an instrument a short handle is provided. This also facilitates placing it in proper position. Anything which enables the operator to dispense with holding the film in position by his bare fingers, unprotected by a pair of *x*-ray proof gloves, or which will allow him to stand entirely away from the patient, is extremely desirable.

A method which has not been practised very much, but which is an excellent one for the upper jaw, is to take a wax impression of the upper jaw just as for making a plate. Put the film in very thin wrappings so as to be quite flexible in the proper position upon this wax impression and replace it in the mouth. This is perfectly retained if the patient closes the mouth gently.

Fig. 579.—Use of the author's vertical film-carrier. Ripperger shield with disk of sole leather in orifice as a protective screen for soft rays.

It is rather desirable that the films should not be bent or curved. Distortion of the image will be apt to occur and this might occasion an error in diagnosis.

Most intelligent adults whom the author has examined by the *x*-ray have been able to hold the film in position with their own fingers.

They must be cautioned against involuntary movements, which would somewhat blur the image.

Conditions Shown by the Radiograph.—The radiograph shows all the conditions mentioned as shown by the fluoroscope and shows them better. In addition it shows the condition of the bone around the root of the tooth; rarefaction caused by ulceration, absorption of the alveolus from Riggs' disease or pyorrhea alveolaris, necrosis and sinus, fracture, neoplasm; also changes in the tooth itself, absorption of the root, pericementitis, pulp-stones; and also the condition of the antrum of Highmore.

Radiography of the Lower Teeth.—For a radiograph of the lower teeth the film is held inside the mouth as nearly parallel as possible to the long axis of the teeth and with its lower edge as low as possible. The patient should face in such a direction that the x-ray will shine between the teeth which are of principal interest, so that their shadows shall not overlap; and the head should be tipped slightly away from the x-ray tube. Except at the sides of the face the degree of curvature of the jaw prevents a single picture from showing more than three or four teeth well.

Interpretation of Dental Radiographs.—Two methods of study are available: first, examination of the film by transmitted light; and second, examination of the print made from the film.

The Film.—This presents a picture in which the densest parts, such as metallic fillings and crown and bridge work, are very light. An object almost totally oqaque to the x-ray produces an almost completely transparent image on the film. The part of the film which has been directly exposed to the x-ray is black and almost opaque. The part which represents the lip is slightly less opaque, and can almost always be seen in the film. The image of the teeth is much more transparent, and appears nearly white by transmitted light. The root-canal and pulp-chamber appear somewhat darker than the body of the tooth.

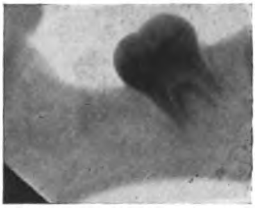

Fig. 580.—Apical foramina flaring in a child's tooth.

Fig. 581.—Apical foramen flaring in an unerupted tooth.

The apical foramen may not be noticeable in a normal adult tooth. It becomes clearly visible if a root-filling or any instrument passes through it (Fig. 587). It shows as a great, wide, flaring opening in a child's tooth (Fig. 580) and in the germ of a tooth long before its normal eruption (Fig. 581, and especially Fig. 614).

The film should, if practicable, be exposed with its sensitized surface toward the *x*-ray tube, and is to be looked at by transmitted light, holding it up between the eye and an open window, or holding it over the smallest frame of a negative examining box. A magnifying glass or "reading glass" may be used with advantage in the latter case. The film-surface being held away from the observer, the picture appears in its proper relations. This is as if the observer were inside the mouth, and should view by light transmitted through the jaw the teeth lying between his eye and the *x*-ray tube. The latter simile applies to the radiographs made upon films held inside the mouth. A film or plate held outside the face should be exposed with its film surface toward the *x*-ray tube during the exposure, and should be examined with its film-surface toward the source of light and away from the observer in order to see objects in their true relation. This is as if the patient's head were transparent and were placed between the observer and a light.

The last case corresponds also to the image seen in the ordinary box fluoroscope or in the author's magnifying fluoroscope.

The Print.—The sensitized surface of the film or plate is placed next to that of the paper, as is always done in making a photographic print, unless there is some special contra-indication. This makes the print correspond exactly to the film when the latter is viewed in the proper way, *i. e.*, with the sensitized surface away from the observer.

A paper should be selected which will give good contrast, and so make pictures which will reproduce fairly well in a photo-engraving if the picture is to be used in illustrating an article. At the same time, the surface should be a smooth one, so that the finer details will not be obscured by the grain of the paper.

"Glossy velox," a paper made by the Eastman Kodak Company, has the proper surface, and has tones varying from white through various shades of gray to black. It gives sufficient detail, and is easy to use because it requires only a few seconds' exposure to an ordinary electric or gaslight. It may be developed by the metolhydrochinon solution that is used for the films.

Prints made upon solio paper require many minutes' exposure to sunlight, as these films are much denser than those produced by ordinary portrait or landscape photography. These prints, however, give somewhat greater detail than the velox paper. They have a brownish-red color and reproduce very well in a photo-engraving. They are less apt to be permanent than the velox prints unless the toning and fixing are very thoroughly done. Ordinary portrait photographs, which gradually fade out, are examples of the lack of permanence found in papers of this class.

The print presents an exact reversal of the lights and shadows of the film. The background should be a pure white, and metallic fillings and crown and bridge work jet black. The teeth are next in darkness, and structure of the bone is gray. The normal antrum appears almost white, and so do large cysts which have been emptied of liquid contents. Pus in the antrum gives a dark appearance at the most dependent portion. An alveolar abscess is seen as a light area around the apex of the root.

The print is the exact duplicate of the fluoroscopic image. The alveolar process and the jaw show less transparency in the film than the teeth, and the details of structure are well shown in a good film. Darker portions in the film or lighter portions in the print indicate less density in the bone.

Lesions Revealed by the x-Ray.—An *alveolar abscess* shows in its very incipiency as a darker area of film (or lighter in the print) surrounding the apex of the root (Figs. 582 to 585).

Two radiographs, made from different elevations[1] (Fig. 586), enable one to locate the abscess cavity as extending in a line with axis of the tooth or toward or away from the surface.

The *x*-ray is useful in locating a tooth or the particular root which is affected by alveolar abscess; also in discovering the cause of irritation in cases of unerupted supernumerary teeth and other unsuspected abnormalities.

Fig. 582.—Abscess at apex of central and lateral incisors, with fistula in roof of mouth.

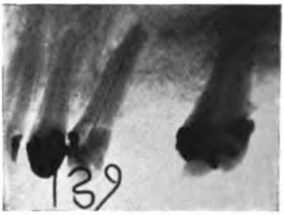

Fig. 583.—Alveolar abscess. Stylet shows patency of foramen.

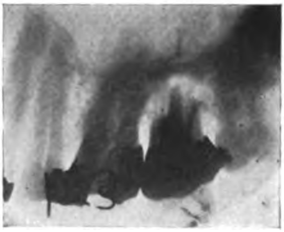

Fig. 584.—Alveolar abscess with imperfect root fillings. Normal antrum.

Fig. 585.—Incipient alveolar abscess of lower first bicuspid and erosion of apex. Second bicuspid root has been squarely amputated by a similar process.

A blurred and lumpy appearance of the root suggests the possibility that the film may have moved during the exposure. Another picture should be made, using extra precautions against this. A perfectly clear picture will usually show whether some lesion has given the lumpy appearance to the root in the blurred picture.

A case of *inflammation* and of loosening of the tooth from an imperfectly fitting crown showed in one of Rhein's[2] radiographs an entirely healthy condition of the alveolar socket.

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[1] Cieszyuski, Fortsch. a. d. Geb. d. Roentgenstrahlen, 1912, p. 207.

[2] Jour. Am. Med. Assoc., July 28, 1906.

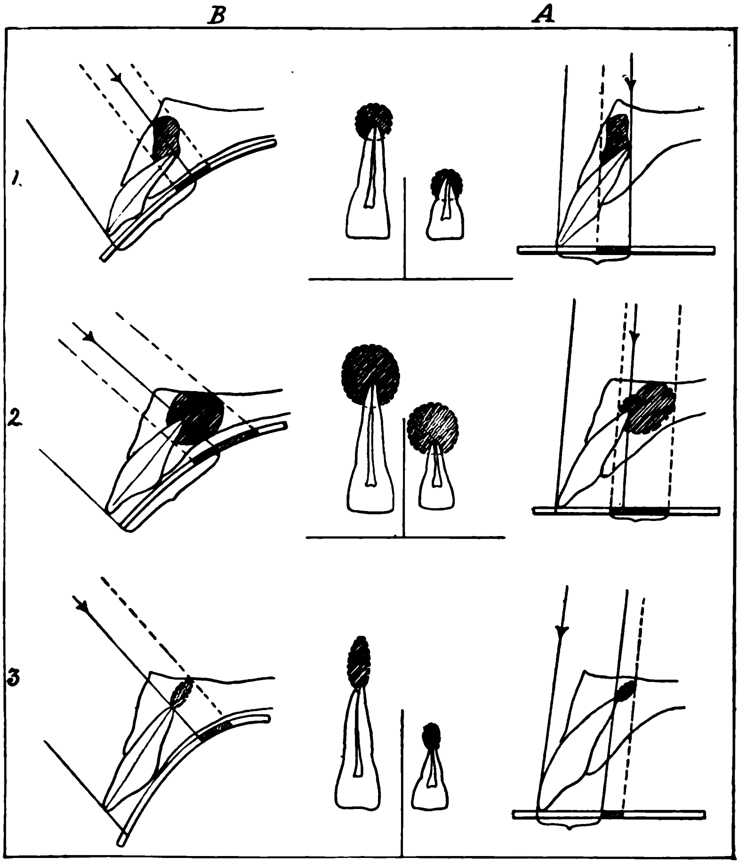

Fig. 586.—Localization of alveolar abscess (Cieszyuski).

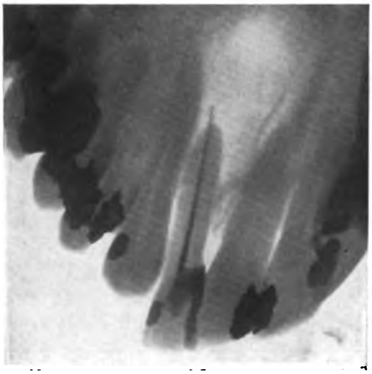

Fig. 587.—Cyst about root of lateral incisor. Stylet placed in root-canal to demonstrate patency of foramen.

A *cyst* or *abscess* cavity in the bone shows as a dark area of film, or a light area in the print, with a clearly defined outline (Fig. 587).

Necrosis shows as a somewhat darker area than the portion of film, or lighter area than the portion of the print, representing normal bone.

Fig. 588.—Necrosis about inferior central incisor.

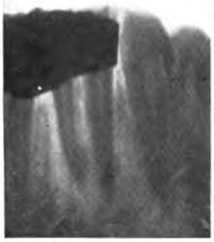

Fig. 589.—Necrosis about root of lower central incisor. Crown and bridge work also shown.

The necrotic area is more transparent to the *x*-ray, which, therefore, darkens the film more than elsewhere. Of course, it is lighter in the print. This difference is only slight, however, and the picture requires interpretation by one familiar with this department of radiography. The structure of dead bone does not appear markedly different from that of normal bone in the radiograph, and there is often no sharply defined outline to the area (Figs. 588 to 593).

Fig. 590.—Necrosis about upper lateral incisor. This tooth had been extracted, the alveolus curetted, and the tooth reimplanted with a porcelain crown. The tooth acted as an irritant foreign body.

Fig 591.—Necrosis of jaw with fistula below chin open for six years, left lower central incisor extracted. Sinus curetted. Cure in fourteen days. (My own patient at St. Bartholomew's clinic.)

A film of the upper jaw, made upon a horizontal plane (Fig. 594), shows markings which correspond to the nasal fossæ and the antra.

One of the author's radiographs (Fig. 595) is of a case of necrosis and fistula, in which a gold probe enters a cavity in an upper central incisor, through the root-canal and the bone, to emerge from the nostril. An interesting feature of this case is the fact that the fistulous tract healed in a couple of weeks after the *x*-ray exposures were made. The case was treated by Dr. Green with the usual antiseptic and stimulant applications, both before and after the *x*-ray examination. The latter was made because the tract had refused to heal, and with reference to a possible operation, the necessity for which was obviated. The author regards it as probable that the exposure to the ray produced a beneficial effect and assisted in effecting a cure.

A case of *necrosis* and *fistula* may be shown by the *x*-ray to be due to a retained broken root of a tooth or to a fragment of root-filling. The soft materials used for root-fillings show as dense bodies in a radiograph.

Fig. 592.—Extensive area of necrosis from neglected alveolar abscess.

Fig. 593.—Necrosis about root of upper central incisor. The large apical foramina and the unerupted teeth show that the patient is a child.

Fracture of the inferior maxilla shows upon a film held inside the mouth (Fig. 596), but the picture is often difficult to make owing to pain. A radiograph made upon a plate held at the side of the face shows the fracture, but usually not very clearly.

Fig. 594.—Markings due to the nostrils, not to necrosis.

Fig. 595.—Probe enters cavity in central incisor, passes through entire length of root, and emerges in nostril.

Fig. 596.—Fracture of lower jaw, between the two bicuspid roots.

Root-fillings are often the subject of investigation by the *x*-ray. They show perfectly well even if of soft material. They should form a continuous opaque mass, occupying the pulp-cavity and the root-canal to the apical foramen. Imperfection may be shown by the opacity not extending to the apical foramen, or by breaks occurring along the length of the filling, or by the filling extending beyond the apical foramen or through the lateral wall of the root.

A root-filling or dressing of cotton would not show in a radiograph.

Fig. 597.—Broken drill in root-canal.

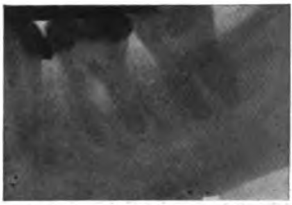

Fig. 598.—Broken instrument perforating the root laterally.

A *broken drill* or broach in the root-canal shows perfectly in a radiograph (Fig. 597).

Metal points may be introduced into the root-canal as far as it can be traced. They will show in the radiograph and one can see whether they are in the root-canal and how much further the drill must be pressed to reach the apical foramen (Fig. 599).

The *x*-ray has often proved of service in the author's hands in the location of the lesion causing a *chronic fistula* when two or three regions were under suspicion. The cause of trouble has frequently proved to be at a considerable distance from the orifice of the fistula.

Fig. 599.—Metal points used to trace the root-canals.

Fig. 600.—Alveolar absorption due to pyorrhea.

Cases of *pyorrhea alveolaris*, or *Riggs' disease* (Figs. 600 to 602) present lesions which show in the radiograph. There may be deep pockets along the root of the tooth from absorption of the alveolar process, and in some cases the process between the roots of two teeth is seen to be almost gone. A pyorrheal pocket shows in the radiograph as a space alongside the tooth, opening at the free border of the gum, and with apparently bare bone and tooth down to the bottom. The normal condition is for the root of the tooth to be seen closely embraced by a distinct layer of tissue, called the peridental membrane, which lines the alveolus or tooth-socket. The alveolar process normally projects between the teeth to about the commencement of the crown; the portion surrounding the root externally and internally does not show in a radiograph, being obscured by the much denser substance of the tooth.

A pyorrheal pocket is sometimes shown by the x-ray to be due to pressure upon the root of the tooth by an unerupted tooth or by a malplaced supernumerary tooth. The pocket in such a case usually forms upon the side opposite to that upon which the unnatural pressure is exerted.

The x-ray is of service in locating the *root-canal* and *apical foramen*, for instance, in cases of commencing alveolar abscess where the dentist's, drill fails to find the proper route. Such a case is illustrated by Fig. 603. There were the pain and swelling and tooth reaction, which indicated the presence of pus at the apex of one of the roots of a lower molar tooth, but nothing to show which root. The drill did not readily follow either root-canal, and the dentist, Dr. Gillett, of course, could not be positive that the canals extended in a perfectly normal direction. It is extremely undesirable to perforate the root laterally. He placed a little metal point in the root-canal as far as it had been traced. The radiograph showed the abscess at the apex of the anterior root, and also showed that the metal point was lying in exactly the right direction. The patient returned to the dentist with the picture in less than an hour. Guided by the picture, the drill was simply pressed straight ahead until something was felt to give way as it entered the abscess cavity. A couple of drops of pus welled up through the cavity in the tooth and the pain was at once relieved.

Fig. 601.—Pyorrheal pocket completely surrounding the roots of a lower molar tooth.

Fig. 602.—Pyorrheal pocket under bridge.

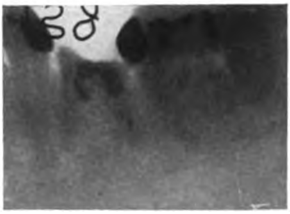

Fig. 603.—Radiograph which served as a guide to the direction of the root-canal in a case of alveolar abscess.

The radiograph is valuable as a guide to the *complete removal of the pulp* from each root to its very extremity.

A *fracture of the root* of a tooth shows as a transverse line, but in the radiographs of the upper central incisors there is normally a transverse marking, which must be taken into account in making the diagnosis.

Curvature of the root is well shown, and one should guard against the production of a false appearance of flexion or curvature, due to bending the film while the radiograph is being made.

The *buccal roots* of the upper molar teeth are difficult to show clearly unless they have root-fillings. The best way to accomplish the desired result seems to be to hold the film up as far as possible on the inside of the mouth, so that the tube will not have to be placed much above the horizontal level of the mouth. A somewhat greater distance, and longer and stronger exposure than usual is required. To make still more certain two radiographs should be made with the tube at decidedly different lateral angles, but still not so far to either side as to cause the images of the adjacent teeth to overlap that of the one under examination. The idea of placing a small x-ray tube inside the mouth and the film on the outside does not seem very practical (see p. 742). We require a much stronger apparatus than any that can be used in this way.

A better plan than this is to place the tube at the opposite side of the face, and at a somewhat lower level, so as to shine through the open mouth and produce a picture upon a film held against the outside of the gums. Such a picture may show also both antra separately.

Fig. 604.—First upper molar root penetrating normal antrum. Pyorrheal pocket around lateral incisor.

Fig. 605.—Empyema of the antrum. The upper teeth had been extracted for supposed neuralgia.

The object nearest the film is always depicted most clearly, and it almost completely obscures the other if the two images overlap. This explains the purpose accomplished by taking the picture of a buccal root upon a film held outside the teeth.

The tube is enveloped in a localizing shield with a sole-leather disk. The anticathode is 11 inches from the film, and the exposure is about thirty seconds, with a penetration of No. 5 Benoist, and an intensity of No. 13 Tousey, or seven and a half seconds with an intensity of No. 15 Tousey.

In making a radiograph of the *upper molars* we are often influenced by a desire to show the relation of their roots to the antrum, and also the condition of the antrum, especially as to the presence of pus. The tube being placed at a higher level than the teeth, the image is apt to be somewhat distorted, and allowance must be made for this in estimating the length of the different roots. The buccal root is apt to seem much shorter than it really is in a radiograph made with the film inside the mouth.

The radiograph will show whether a root penetrates the antrum, as in Fig. 604, but in a case in which the floor of the antrum dips down between the lingual and buccal roots the radiograph would seem to show both roots extending into the antrum.

Disease of the Antrum as Shown Upon a Small Film Held Inside the

Mouth.—A horizontal film, like Fig. 604, or a vertical one, like Fig. 606, will show almost the entire extent of one antrum. The air space should seem very transparent as compared with the dense teeth and even the less dense jaw structure. A marked degree of opacity in the antrum means pus or polypoid or granulation tissue. It was due to pus in Fig. 605, which is of the patient whose large radiograph of all the pneumatic sinuses is given at p. 889. All his upper teeth had been removed for pain, which was thought to be of neuralgic origin.

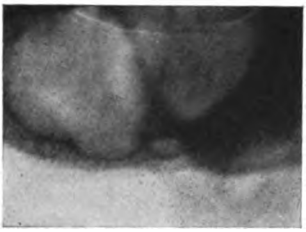

Fig. 606.—Normal antrum. Small film held vertically in mouth. Case of neuralgia with all upper teeth extracted.

Fig. 607.—Normal antrum. Spiculæ of bone have been removed along the alveolar margin. Horizontal film. Case of neuralgia.

A large plate, showing the entire face, either laterally or anteroposteriorly, is a necessary part of the examination in most cases. It shows the extent to which the disease has involved the other pneumatic sinuses.

Tinnitus aurium was the symptom which led to an x-ray examination in one of Schamberg's cases. The radiograph showed pyorrheal pockets about the roots of some of the teeth communicating with the antrum by a small opening. Extraction of the affected teeth and syringing the antrum cured the ear symptoms.[1]

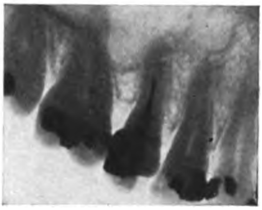

Fig. 608.—Normal antrum with old abscess area about second bicuspid and first molar.

The roots of the teeth do not usually extend beyond the level of the hard palate. The portion of the upper jaw below that level is the alveolar process and is absorbed after the teeth are lost.

A tooth which has been injured in any way, or which has been extracted or knocked out and reimplanted, may present symptoms pointing to absorption of its root. Several such cases have been examined by the author, and in each case the radiograph has shown whether there has been any absorption, and, if so, to what extent (Fig. 609).

The radiograph will show the condition of the roots of teeth which form the anchorage for or are held in place by crown and bridge work (Fig. 610).

The roots of a crowned tooth may be examined to determine the degree of absorption which has taken place.

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[1] Jour. Am. Med. Assoc., June 30, 1906, p. 1990.

Changes in the Nerve or Pulp of a Tooth.—A slight irritation will not be recognizable by the *x*-ray, but if it is severe it will produce an area of translucency around the apex of the root indicating an incipient alveolar abscess.

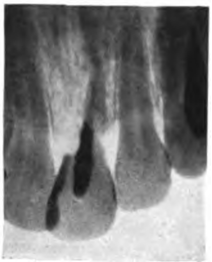

Fig. 609.—Superior central incisor reimplanted nine years ago. Considerable absorption of root.

Fig. 610—Pulp-stone. The calculus could be readily seen in looking at the film by transmitted light.

Pulp-stones.—These concretions show as very defined opaque objects in the pulp-cavity of the tooth. They sometimes, as in Fig. 610, look like exostoses from the bony wall of the pulp-chamber.

Cysts at the Roots of Teeth Causative of Tuberculosis.—Chronic abscesses at the roots of teeth have been observed by J. Zilz[1] as an active starting-point for tuberculosis.

X-ray Findings in Cases of Unerupted Teeth.—The unerupted superior canine (Fig. 611) is usually found to be present, and generally lies in a direction more nearly parallel with the median line than normally, and usually on the lingual side of the other teeth. If it presses against the root of the lateral incisor a cyst cavity (Fig. 611) is often to be seen there. The unerupted lower third molar is almost always found and frequently impacted (Fig. 612).

Fig. 611.—Man aged forty-six. Canine just erupting. Artificial tooth in position. Previously unsuspected cyst about root of lateral incisor.

Fig. 612.—Impacted lower wisdom tooth.

The other molars and the bicuspids if much delayed in eruption are

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[1] Beitrage zur klinik der Tuberkulose, Wurzburg, xxii, Nov. 2; Jour. Am. Med. Assoc., May 4, 1912, p. 1404.

fully as apt to be found entirely absent as to be present. It is a very serious mistake to extract a persistent temporary tooth in any of these locations, as was done in Fig. 613, without first using the *x*-ray to find out whether the permanent tooth is present.

A question sometimes arises as to whether a certain tooth is a persistent temporary molar or a permanent bicuspid. A radiograph of the tooth shows which it is, and if it is a persistent temporary tooth the picture shows whether the germ of the permanent tooth is present (Fig. 614) or absent (Fig. 615).

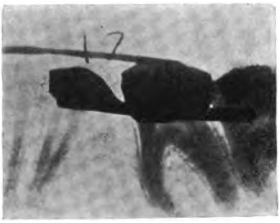

Fig. 613.—Absence of second lower bicuspid. Persistent temporary molar extracted.

Fig. 614.—Persistent temporary lower molars with unerupted bicuspids. Imperfect technic. Should extend lower.

Radiographic examinations show that absorption of the root of a temporary tooth is not entirely due to pressure of the oncoming permanent tooth, but is a natural process which sometimes occurs when the permanent tooth is completely absent (Figs. 616 and 617).

The most remarkable case in the author's experience is that of a young man, a patient of Dr. Allan, who at the age of twenty years still had every one of his first teeth. A series of radiographs, including Fig. 618, revealed the presence of all the permanent teeth still unerupted. The smallness of the first set of teeth gave an infantile expression to the face, so for looks a complete set of false teeth, upper and lower, were worn. The patient was thus going around with three complete sets of teeth.

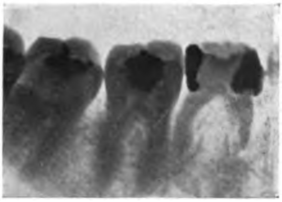

Fig. 615.—Persistent temporary lower molar. Absence of germ of permanent second bicuspid.

Fig. 616.—Persistent temporary upper lateral undergoing absorption, although the permanent germ is absent.

The radiograph will locate an unerupted second molar and show whether it is obstructed or is pressing upon the first molar. Such an examination would be desirable, as suggested by Hopkins,[1] in the case of a child of ten or twelve years suffering from fretfulness and loss of appetite, with irritated eyes and ears, anemia, and nervousness bordering on hysteria.

Unerupted teeth are often seen to lie in a kind of capsule, and very valuable information as to their probable period of eruption may be gained from the degree of development of the tooth. This is perhaps more important than its proximity to the surface.

Fig. 617.—Persistent temporary upper molar undergoing absorption, although permanent germ is absent.

Fig. 618.—Portion of upper jaw in a case with all temporary teeth persistent at the age of twenty years.

Prolonged Retention of Deciduous Teeth or Their Roots.—The roots of these teeth sometimes fail to be absorbed and deflect the oncoming permanent teeth. A radiograph will show whether the roots in question are undergoing absorption or not.

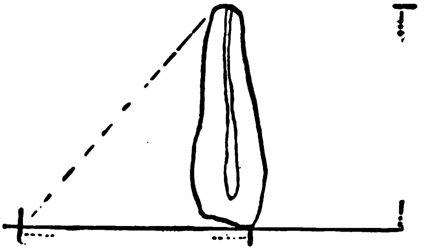

Fig. 619.—Angle at which the *x*-ray must be directed in order that the image of a tooth upon a horizontal film shall be about the actual length.

Flint[2] cites many ways in which the *x*-ray gives valuable information in orthodontia.

Radiographic Measurement of the Permanent Teeth Before Eruption to Provide for Early Regulation of the Dental Arch if Their Size Necessitates it.—This was the title of an article read by the author before the N. Y. Institute of Stomatology, November 9, 1906. It was suggested by Hawley's investigations in regard to the relation between the size and shape of the dental arch and the size of the different permanent teeth. Dr. Gillett called my attention to the advantage to be derived from an accurate measurement of the different permanent teeth a year or two before their eruption. Acting upon this idea, the author has made radiographs of the temporary and unerupted permanent teeth in about 100 children. While there was every reason to believe that such pictures would give an idea of the relative size before eruption, it seemed very desirable, indeed, to make a series of measurements to find out also how much magnified or reduced the *x*-ray image of the erupted teeth was

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[1] Jour. Am. Med. Assoc., June 30, 1906, p. 1989.

[2] Dr. D. W. Flint, Dental Cosmos, Nov., 1907.

as compared with measurements made at the same time from the actual teeth themselves. The teeth which had already erupted were measured by means of a caliper square, graduated in hundredths of an inch, and at another time, without reference to these measurements, others were made of the same teeth as represented in the


Fig. 620.


Fig. 621.


Fig. 622.


Fig. 623.


Fig. 624.


Fig. 625.

Figs. 620–625.—Radiographs used in measuring the width of the upper or lower central incisors before eruption to provide for early regulation in case these teeth are too broad for the arch. In Fig. 623, where one central had erupted and the other had not, the radiographic measurements were equal. In such pictures as 624 it is easy to see that only the width of the central incisor or tooth to our right is correctly shown. The one to our left is viewed from the side.

radiographs. The lateral measurements corresponded to within $\frac{1}{100}$ inch. For our purpose, it is fortunately not necessary to have an exact means of measuring the actual vertical length of the teeth. A reasonable degree of accuracy, however, can be obtained by holding the film and the tube at the proper angle (Fig. 619). It is very noteworthy that the radiographs show that the size of the temporary teeth does not furnish any accurate indication of the size of the permanent unerupted teeth. Some of the largest unerupted permanent upper central incisors are found in cases in which the corresponding temporary teeth are medium or small. (Figs. 620 to 625 are examples of this work.) The radiographs and measurements have been made especially in children of from four and a half to seven years of age, and in these cases attention has been directed chiefly to measurements of the upper and lower incisors. The author has also taken an impression of both upper and lower dental arches by having the child bite upon a sheet of wax placed horizontally in the mouth. Another class of cases in which radiographic measurements are valuable are the patients of young or middle age who have persistent temporary teeth, and in whom the x-ray reveals the absence of the permanent tooth or, if it is present, shows its size and direction. Closely akin to these are the cases in which the natural loss of the temporary tooth has not been followed by the eruption of the permanent tooth. In both of these classes of cases the relative size of the unerupted tooth, as compared with the adjacent permanent teeth shown in the picture, gives at a glance the indication for proper spacing in order to allow of its eruption, and measurements in hundredths of an inch or fractions of a millimeter are not usually required.

Fig. 626.—Calipers measuring the radiographic image of the unerupted lower central incisors.

The author is indebted to Dr. J. Lowe Young for making measurements of the actual teeth in several of these cases, and for suggestions as to the selection of the instruments used for such measurements.

At a clinic given before the National Dental Society, Washington, 1912, the author reported further upon this method:

Imperfect development of the teeth is not only a disfigurement, but renders proper mastication impossible and the proper action of the saliva unlikely. The immediate effects are starchy indigestion and irritation from unmasticated meat with auto-intoxication from both.

In the young child "the nasal passages are lined below, in front, and on both sides by the germs of the teeth" (Dr. Strang), and imperfect

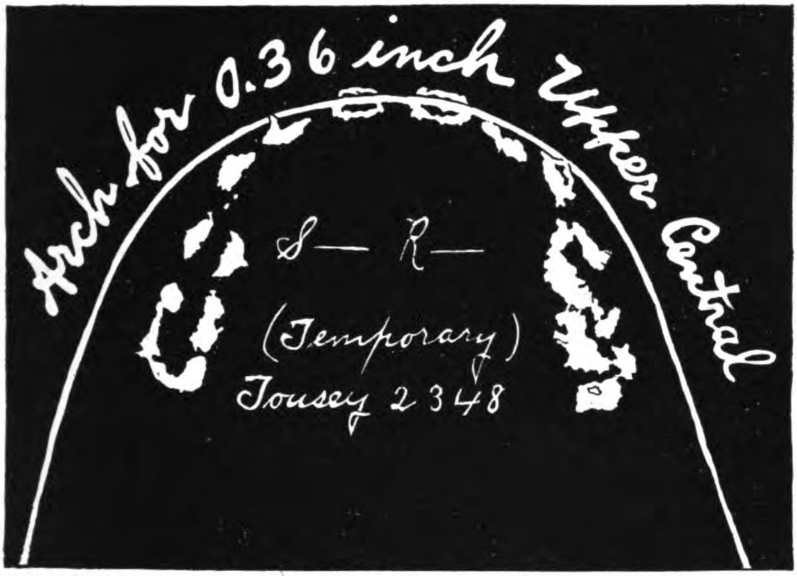

Fig. 627.—Narrow curve formed by the temporary teeth in a case in which the permanent teeth were shown by the *x*-ray to require a broad curve.

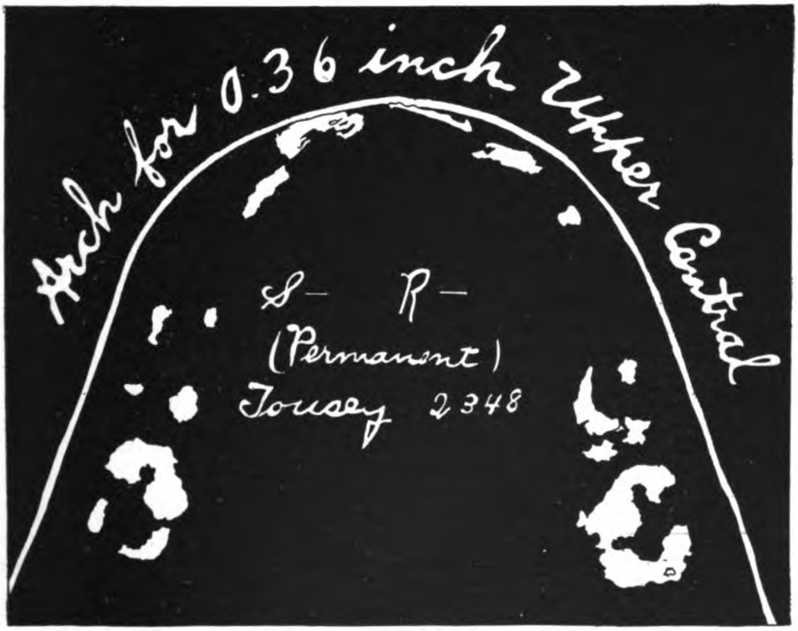

Fig. 628.—Curve formed by the permanent teeth in the same case as Fig. 627 is still too narrow for permanent teeth of that size.

development of the teeth and of the maxillary bones supporting them occasions maldevelopment in the bony walls of the nasal passages and the accessory pneumatic sinuses of the face, and the effect of underdevelopment may even extend to the cranial cavity and the brain.

Deviations of the septum and mouth-breathing, unrelieved by the removal of adenoids and tonsils, are among the results of maldevelopment of the teeth with a too narrow and too highly arched hard palate.

The object of my most recent work has been to determine beforehand the presence and position, and especially the size of the permanent teeth, before the loss of the temporary teeth. The latter may be quickly and easily trained to a curve of the proper radius and will then guide the permanent teeth into proper position.

ACTUAL WIDTH OF TEMPORARY AND PERMANENT CENTRAL INCISORS (THE LATTER MEASURED SOME YEARS LATER) IN HUNDREDTHS OF AN INCH.

Name.	Age at first measurement (years).	Age at second measurement (years).	Weight at second measurement (pounds).	Right upper central.		Ratio 1 to	Left lower central.		Ratio 1 to
				Temporary.	Permanent.		Temporary.	Permanent.	
Matthew S.	6	8	..	25	38	1.52	15	24½	1.63
Clara T.	5	10	85	24	36	1.50	15½	22	1.42
Cecelia L.	7	9	..	21	33	1.30	...	21	
Gretchen W.	5	10	73	25	29	1.16	14	19	1.36
Margaret F.	5	10	72	25½	33	1.25	16½	21	1.28
Florence F	5	10	63	25	34	1.36	14	21	1.50
Sissie R.	5	10	60	23	36	1.57	11	23	2.09
Jeanette S.	6	8	..	22½	31	1.38			
Nora F.	6	6			35				

Actual measurements of the temporary teeth bear no fixed ratio to actual measurements of the permanent teeth. In a series of 7 cases, shown in table above, the ratio varied 30 per cent; in the same cases untreated, the curve of the temporary arch, whether suitable for the permanent teeth or not, was reproduced in the permanent arch. *X*-ray measurements of the width of the unerupted permanent upper and lower central incisors at the age of five or six years correspond within $\frac{1}{100}$ inch with the actual measurements of the same teeth five years later, after eruption, as shown in the following table.

PERMANENT CENTRAL INCISORS MEASURED RADIOGRAPHICALLY BEFORE ERUPTION AND ACTUALLY SOME YEARS LATER AFTER ERUPTION. (Numbers are in Hundredths of an Inch.)

Name.	Tooth.	Radiograph unerupted.	Actually after eruption.
Matthew S.	Left Upper Central	39	38½
Clara T.	Right Upper Central.	36	36
Clara T.	Right Lower Central	22	22
Cecelia L.	Right Upper Central	34 oblique	33
Gretchen W.	Right Upper Central	29	29
Florence R.	Right Upper Central	35	34
Sissie R	Left Upper Central	36	36
Jeanette S.	Left Upper Cnetral.	32	32
Jeanette S.	Right Lower Central.	21½	22

The author's technic is as follows: The temporary centrals are measured with a sharp pointed caliper square with a screw adjustment, and graduated in hundredths of an inch. A wax impression of the curve of the temporary upper and lower arches is made. Radiographs, or *x*-ray pictures (Figs. 627 and 628), are made of the unerupted upper and lower central incisors and the width of the images of these teeth is measured (Fig. 629). A curve suitable for permanent teeth of this size is calculated by a modification of Hawley's and Bonwill's tables. My work shows the size that the permanent teeth will have and the radius of the curve required to accomodate them. The temporary bite is photographed with the actual curve formed by the cutting edges of the incisors, the cusps of the canines, and the buccal cusps of the bicuspids and molars, and upon the same photograph is drawn the correct curve (Fig. 630) to accommodate permanent teeth of the size determined by the *x*-ray. The orthodontist may regulate the temporary teeth to this curve, and so guide the permanent teeth into proper position as they erupt. Figure 628 shows the same case as Fig. 627, in which the temporary curve was too small for permanent teeth of the size shown by the *x*-ray. The case was untreated, and five years later the curve formed by the erupted permanent teeth was a contracted one of the same radius as that originally formed by the temporary teeth.

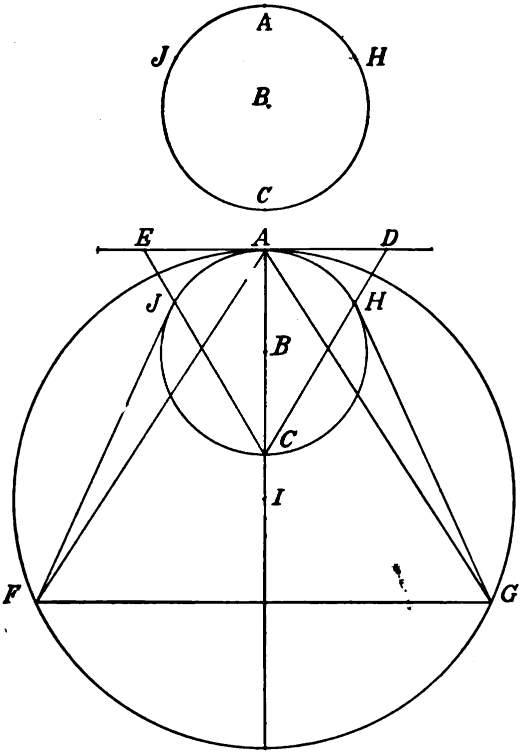

Fig. 629.—Calculation of permanent dental circle from *x*-ray measurement of the upper centrals.

Take the width of one permanent upper central incisor, double it, and add 0.24 inch to get the radius of the circle formed by the six upper front teeth (cutting edge of incisors and cusps of canine). Add 50 per cent. to that, and you have the distance in a straight line from the middle of the anterior surface of the first permanent upper molar to the space between the two centrals.

After drawing the circle use the radius from *A* to get the distal points of the canines *J* and *H*. From *C*, draw lines through *J* and *H* to the tangent and so get *E* and *D*. Use *E D* as radius of a circle whose center is at *I*. Starting from *A* in both directions measure off the length of the radius six times and so get the inscribed isosceles triangle, *A*, *F*, *C*. Draw lines *H*, *C* and *J*, *F*. The outer cusps of the bicuspids and molars lie along these two straight lines.

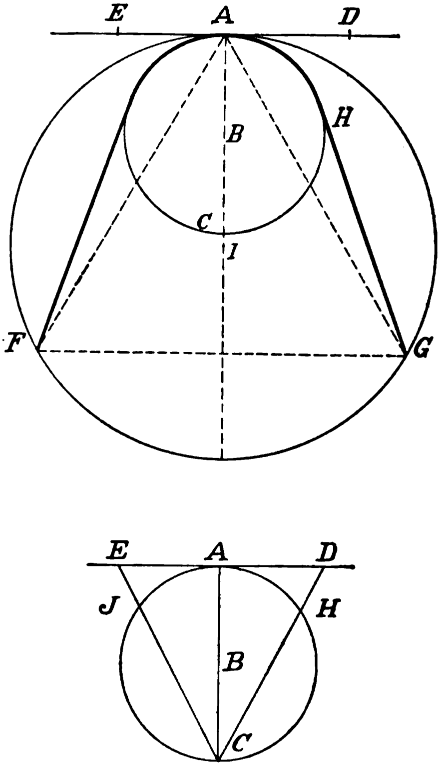

Fig. 630.—Curve of the permanent dental arch calculated by Tousey's method from *x*-ray measurement of the permanent upper centrals. *E*, *D* is taken as the radius *A*, *I* of the large circle. Of course, the teeth do not extend anywhere near as far back as *F* and *G*.

Stereoscopic Radiographs in Dental Work.—Two types of radiographs are available: one upon two successive films held inside the mouth, and the other upon two successive films, or plates, held against the outside of the face. The latter pictures, like Fig. 631, *A* and *B*, take in a wide area and show the topography of the teeth, upper and lower jaws, and tongue in their natural perspective. The pictures may be made upon small films held inside the mouth when the perspective of the roots of an individual tooth, or that of the roots of adjacent teeth, or of an unerupted tooth and the roots of the neighboring teeth, is desired. The object in the latter case is to find out whether the unerupted tooth is on the buccal or the labial aspect. It is easy to misinterpret a pair of these little stereoscopic pictures if they are pasted in the wrong positions upon the card, so that the left eye looks through the stereoscope at the picture which should be placed before the right eye.

The small stereoscopic pictures are made in the same way as dental radiographs, except that two separate exposures are made upon successive films held in exactly the same position inside the mouth, while the tube is moved 2½ inches laterally before taking the second picture.

This is the proper displacement for radiographs made upon a horizontal film, with the anticathode about 13 inches distant from the film. A displacement of 3 inches is better where an external plate is used and the distance is about 16 inches. Both of these yield good results, because the relative position of the patient and the film or plate and the *x*-ray tube may be exactly duplicated. They both show the perspective of a large part of the jaw, and the position of the unerupted as well as the erupted teeth.

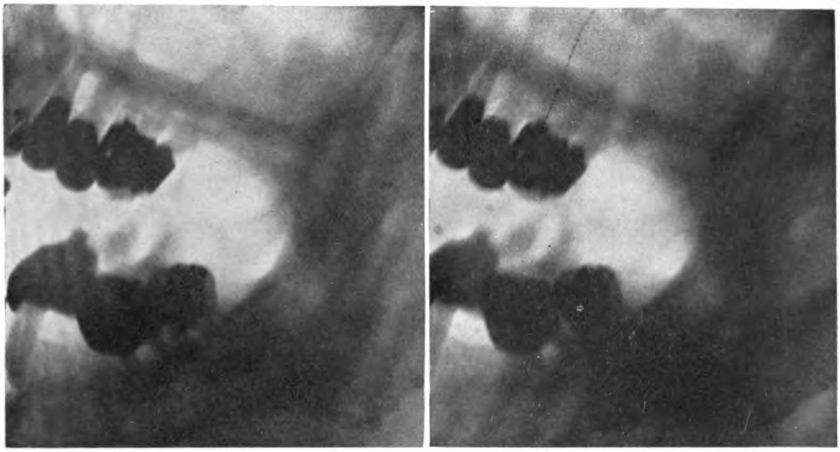
A *B*

Fig. 631, *A*, *B*.—Stereoscopic radiograph of the upper and lower jaws.

The smaller films, held parallel with the axis of the teeth, present greater difficulties in securing the same relative position of patient and film and *x*-ray tube, and are, therefore, less apt to yield satisfactory results. The anticathode should be 13 inches from the film, and should be displaced 4 inches before the second picture is made. These pictures, if successful, show the perspective of parts of an individual tooth, and, for example, would reveal the fact that a root-filling perforated the root either buccally or lingually.

Fig. 632 shows the principle upon which this is based. The position of the tube in the first picture is marked T^1 and in the second picture T^2. Two bodies at different distances from the film are marked by a square (□) and a triangle (△) cast, the images marked (□^{1}) and (△^{1}) in the first picture and $(\square^2)$ and $(\triangle^2)$ in the second picture. These four images are not all upon the same film; $(\square^1)$ and $(\triangle^1)$ are upon one film, and the other two upon the second film.

A moment's study will show that motion of the tube in one direction displaces the images of all bodies in the opposite direction. Objects at a distance from the film undergo greater displacement than those near it. Examining the two pictures, we should find that the image of the object further from the film is displaced in the opposite direction (with reference to the object nearest the firm) from that in which the tube is shifted. The author likes this method of studying the two small pictures better than by combined vision with the stereoscope.

If the stereoscope is to be used care must be taken to hold the film with its sensitized surface toward the x-ray tube. The print made from the film exposed with the x-ray tube farthest to the patient's left should be pasted upon the card so as to be looked at with the observer's right eye, and the print from the other film is looked at with the left eye.

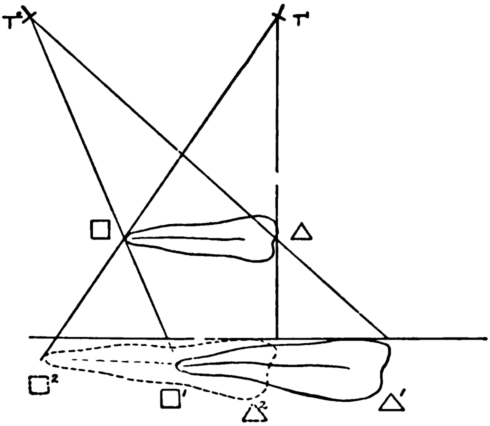

Fig. 632.—Principle of stereoscopic radiography.

The perspective is then as if the observer's eyes, placed in the two positions of the x-ray tube, looked at a transparent jaw. Objects which look farthest away are on the lingual aspect; those that look nearer are on the buccal aspect.

Determination of Perspective in a Single Radiograph of the Teeth.—The determination of the relative position of two teeth whose images overlap each other can usually be made by a careful study of a single radiograph. The image of the tooth nearer the plate is markedly more distinct and clearly defined. Fig. 633 shows this fact. The image of the unerupted canine is only rendered denser by the presence of other teeth, while the images of the latter are obscured and rendered less easy to trace where the overlapping occurs.

Where the images of the adjacent borders of two teeth overlap in an x-ray picture the image is more than twice as dense as that of either of the thin borders alone. Successive portions of dense substances absorb more and more of the rays which have an effect upon a sensitized film. After traversing a certain thickness of dense tissue the radiation produces no visible effect upon the film.

Radiography of the Inferior Dental Nerve.—Radiographs of the bony canal which this nerve traverses in the lower jaw may be made in two ways.

A film $1\frac{1}{4}\times 2$ inches long may be held inside the mouth and pressed closely against the inner surface of the jaw from the region of the canine tooth backward. The upper margin of the film should not be above the crowns of the teeth, while the lower margin should extend well below the roots. The *x*-ray tube should be at the same side of the face and opposite the second molar tooth at a distance of 14 inches from the anticathode to the film. The *x*-ray should be of a high degree of penetration, No. 8 Benoist, and the exposure will be twelve seconds with a 12-inch coil or about one-fourth second with an unfluctuating converter or a transformer. The object is to obtain a picture showing as great detail as possible in the bony structure of the jaw, even at the expense of a certain degree of contrast in the radiograph.

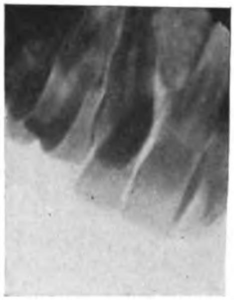

Fig. 633.—Lady thirty-two years old. Unerupted canine. Temporary canine still *in situ*. Radiograph taken to determine position and direction of unerupted canine.

Fig. 635 shows a gold plug in the inferior dental canal. It was placed there six years previously, to prevent regeneration of the nerve after resection. It could be seen very well with an ordinary fluoroscope and the *x*-ray tube held at the opposite side of the face. It seemed to be acting as an irritant foreign body.

The other method is to make a radiograph on a plate held at the outside of the jaw with the *x*-ray tube at the opposite side of the face.

Fig. 634.—Inferior dental canal in case of neuralgia. The teeth had been extracted long before.

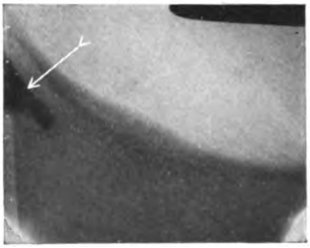

Fig. 635.—Arrow points to gold plug placed in inferior dental canal after resection of the nerve.

The tube may be at such a level as to shine from under the opposite side of the jaw (Fig. 636), or it may be directly opposite and shine right through both sides, but so near that while the image of the affected side is clearly defined that of the opposite side is enlarged and vague. In either position the exposure should be rather long and strong, and the degree of penetration rather high—penetration, No. 8 Benoist; exposure forty seconds with a 12-inch coil, or about one second with a transformer or an unfluctuating converter.

No abnormality of the bony canal is ordinarily found, but the radiograph often reveals an unsuspected source of trouble in the teeth or jaw.

Radiography of the Inferior Maxilla.—Under this heading may be described the making of a picture upon a plate held against the outside of the face, the tube being at the opposite side of the patient. Such a picture does not give as good an image of any of the teeth as the other method, but it does enable us to radiograph the articulation of the jaw and to examine the condyle and ramus of the jaw for a fracture.

Three methods are excellent: *First,* a pair of stereoscopic radiographs, anticathode 20 inches from the plate, and vertically over the external auditory meatus in one picture, and over the front of the mouth in the companion picture. Distance 20 inches, exposure for each picture four minutes with 5 amperes, or two minutes with 10 amperes, or one minute with 15 amperes and medium vacuum, or one or two seconds with a transformer or an unfluctuating converter. Further details of this method are given under the head of stereoscopic radiography. As applied to the face it gives good anatomic detail, for instance, of the various pneumatic sinuses.

Fig. 636.—Radiography of the inferior dental nerve upon a plate outside of the face. The stereoscopic plate-holder is shown. The plate in its opaque envelopes can be exchanged for another without any movement on the part of the patient.

Second, the tube and the head may be so placed that the x-ray will shine under the opposite side of the jaw and through the floor of the mouth and the affected side of the jaw, the plate being at that side of the face. With a little care a picture may be obtained in which the details of almost the entire ramus and half of the body of the lower jaw are shown, the image of the opposite side of the jaw falling at a higher level on the plate. The exposure is the same as for the previous radiograph.

Third, the author's screen for soft rays may be used, enabling the anticathode to be brought within 8 or 10 inches of the plate, the image of the side next to the plate being sharp and clear and very little affected by the enlarged and indistinct image of the opposite side. This is the method of choice for fractures and for the articulation, and may be used for obtaining a radiograph of the teeth if for any reason it is impossible to use the better method of placing a film inside the mouth. The plate is at the side of the patient's face and the tube directly opposite, enveloped in a localizing shield with the author's screen for soft rays brought almost in contact with the face. Exposure the same as for the previous radiograph.

Fig. 637.—Normal articulation of the inferior maxilla with the mouth partly open.

Radiographs of the normal articulation of the lower jaw (Fig. 637) taken with the mouth closed or only slightly opened show the condyloid process within the glenoid fossa. With wider opening the condyloid process is seen to leave the glenoid fossa and to go downward and forward upon the eminentia articularis. A dislocation is shown as an exaggeration of this normal displacement to a point beyond the eminentia articularis.

The conditions revealed by the *x*-ray in a typic case of long-standing ankylosis of the jaw are described by Cryer.[1] The angle of the chin, or mental process, is drawn back and the angle of the jaw downward. These are due to imperfect development under the abnormal conditions.

The *x*-Ray in the Differential Diagnosis of Facial Neuralgia.—The *x*-ray has an undoubted action in relieving pain, as shown in cancer and rheumatism, and it is effective in many forms of neuralgia. There are certain cases in which the nature or the position of the pathologic lesion renders a cure impossible except by surgical removal of the cause of the trouble. The *x*-ray will often be of service in the differential diagnosis of neuralgia.

Fig. 638.—Unerupted lower molar causing severe facial neuralgia.

A case illustrating this is shown in Fig. 638. The patient, a lady about fifty years of age, was sent to me for Röntgen diagnosis by Dr. N. B. Potter of this city. She had suffered for three years from very severe pain near the angle of the lower jaw, all the teeth except the last molar had been extracted from that part of the jaw without relief. Medical treatment, phototherapy, and electrotherapy had been applied by

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[1] Dental Cosmos, Jan., 1905, p. 15.

specialists in New York and Paris without success. An operation was under consideration for removal of the Gasserian ganglion, or of the origin of the third division of the fifth cranial nerve. The radiograph was taken with the affected side of the patient's face lying upon the plate and with the *x*-ray tube above the opposite side of the face. This showed a large molar tooth imbedded in the jaw-bone behind the only visible molar and growing against its root. The operation for the removal of such a tooth was a serious one, and followed by suppuration requiring external incisions. There has been gradual improvement since recovery from the effects of the operation. Change of climate and attention to the general health promise a cure. The menopause may have had something to do with the neuralgia.

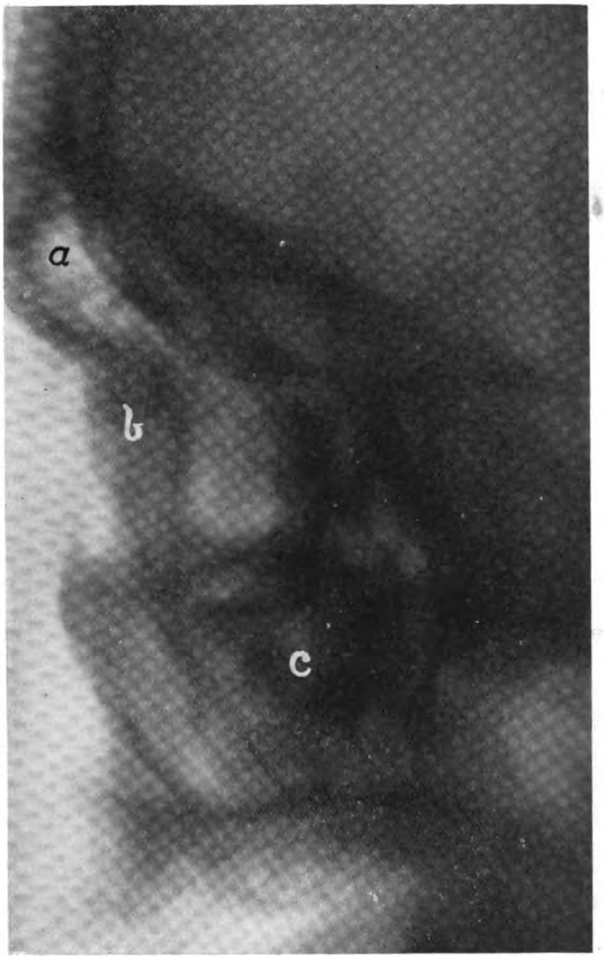

Fig. 639.—*c*, Chronic empyema of the antrum; the clear space to the right of *b* shows ethmoid cells scraped out for suppuration.

Another illustrative case is the one shown in Fig. 639. The patient is himself a physician, and had suffered for some years from pain in the upper jaw. All the upper teeth had been extracted, and at various times spiculæ of bone had been removed from the maxilla. He continued to suffer from pain, and was unable to wear a set of false teeth for more than an hour at a time. The *x*-ray examination included a number of radiographs from different directions. The one reproduced reveals the nature of the case clearly. This radiograph was made with the chiefly affected side of the face lying upon the plate and with the tube over the opposite side. It showed an area of opacity where the normal translucency of the antrum, or maxillary sinus, should have been. This was due to chronic suppuration in the antrum, which was cured by an operation performed by Dr. Cryer.

An *x*-ray examination in an obstinate case of neuralgia about the face should exclude suppuration or polypoid growth in the antrum; cyst, abscess, or tumor of the maxilla; retained broken roots of teeth; unerupted teeth, especially third molar teeth; and the different lesions which may affect the root or the root-canal of a tooth or its alveolus; and the presence of a foreign body, such as a broken drill or a part of a root-filling, piercing the root of a tooth and projecting into the alveolus. The inferior dental nerve is liable to compression or irritation during its passage through its bony canal, and a good radiograph of this part of the jaw is often of the greatest value.

Certain intracranial conditions would be sought when the clinical history suggested such an examination. The *x*-ray reveals the presence of tumor, or abscess, or hematoma of the brain, osseous tumor, sinusitis and pachymeningitis. Benedikt has especially studied the radiographic appearance of intracranial lesions.

The *x*-Ray in the Diagnosis of Disease of the Pneumatic Sinuses of the Face.—The fluoroscope shows the size and shape of the different sinuses, and also whether they form the normal air spaces or are made more opaque, for instance, by pus. Such an examination, however, is not depended upon for two reasons: the *x*-ray would have to be very perfectly applied to produce a first-class fluoroscopic image and an accurate diagnosis of the frontal sinus, and would require so long a study as to be unsafe. Some operators, however, like Caldwell, make a very brief fluoroscopic examination to see whether everything is adjusted for the best possible radiograph. This, however, is undesirable unless absolutely necessary.

Radiography of the Frontal Sinus.—The radiograph may be made either from a lateral or an anteroposterior direction.

Lateral.—The plate is to be at one side of the patient's head and the *x*-ray tube at the other, the normal line passing through the frontal sinus.

The position of the patient's head is partly a matter of convenience. The plate, for instance, may be horizontal, and the patient lie with the side of his face resting upon it (Fig. 640). Or the author's lateral plate-holder may hold the stereoscopic plate-carrier in a vertical position, while the patient lies face upward with the side of his head close against the plate-carrier. This apparatus makes it easy to make a preliminary fluoroscopic examination in exceptional cases, and makes it easier for the operator to protect himself from the *x*-ray than if the *x*-ray tube were below the head and the screen held over it.

The anticathode of the tube should be at a distance of 12 or 14 inches from the plate. The degree of penetration should be No. 6 or No. 8 Benoist; the exposure from forty to sixty seconds, with a 12-inch coil or from one-fourth to one second with a transformer or an unfluctuating converter. Much less intensity cannot be relied upon for a good picture, even with a greater length of exposure.

It is very convenient to have the tube enveloped in a localizing shield which limits the rays to the required direction, and which the author supplements by the use of a sole-leather disk to arrest the soft rays.

The indications to be gathered from a lateral radiograph of the frontal sinus relate chiefly to its condition near the median line where it is seen in profile. Its anteroposterior and its vertical measurements are rendered visible, and the radiograph shows whether this part of the frontal sinus is occupied by air or by some opaque substance like pus.

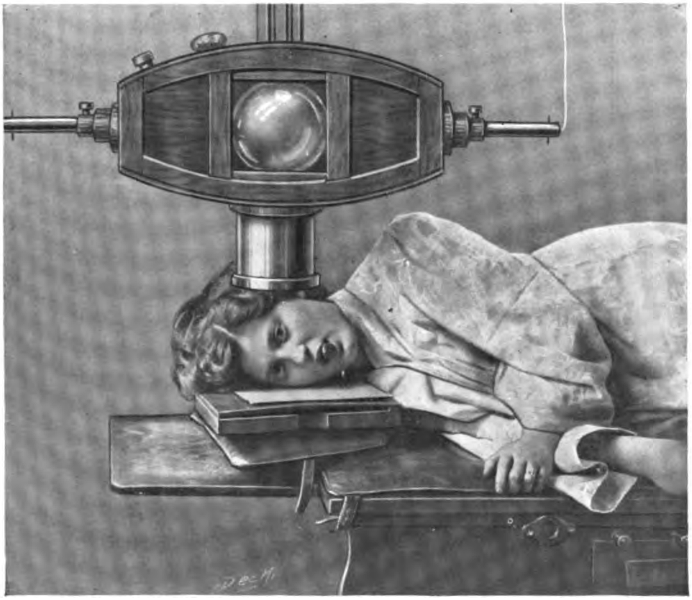

Fig. 640.—Radiography of the frontal sinus, from the side.

In one of the author's radiographs (Fig. 641) the posterior wall of the frontal sinus shows irregular sharp bony points and the infundibulum shows very well.

A lateral radiograph of the frontal sinus is usually so distinct as to show well both in the plate and in a print made from it.

Harland and Pancoast[1] have made successful lateral radiographs of the frontal and other pneumatic sinuses by using a high degree of vacuum. Distance, 18 inches; primary current for induction-coil, 13 to 18 amperes; exposure, twenty-eight to thirty-three seconds. With an unfluctuating converter or a transformer the exposure is from one-half to one second.

Anteroposterior radiographs of the frontal and maxillary sinuses and

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[1] Med. Soc. State of Pennsylvania, Sept., 1906; Jour. Am. Med. Assoc., Oct. 6, 1906.

the ethmoid cells were, I believe, first successfully made in Killian's clinic at Freiburg.

It is essential to use a small diaphragm or cylinder for this work.

Coakley, of New York, has exhibited many plates of excellent anteroposterior radiographs of the frontal sinus made, under his direction, I believe, by Caldwell and others.[1] Loeb, of St. Louis, has also done similar work.

The radiograph should show the orbits, the nasal bones, turbinated bones, traces of the sagittal suture in the frontal bone, and coronoid suture. The size and shape of the frontal sinus can be determined, also the position of the septum and of any accessory septa.

Fig. 641.—Lateral radiograph of frontal sinus showing the infundibulum.

Coakley's[2] conclusions are: First, it is possible by means of a skiagraph to determine the presence or absence of a frontal sinus which extends vertically above the glabella Second, a frontal sinus may be small, parallel with the upper, inner margin of the orbit and not detected in the skiagraph. Third, in all cases of unilateral disease of the frontal sinus verified by operation a cloudiness has been observed in part or all

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[1] American Laryngological Association, 1906; British Medical Association, 1906, and Brit. Med. Jour., Nov. 17, 1906.

[2] Transactions American Laryngological, Rhinological, and Otological Society, 1905, p. 490.

of the area occupied by the sinus, and an indistinctness in the outline of the cavity as compared with the opposite or healthy side.

This is a very much more difficult radiograph to make, and even the most expert radiologist may expect a certain number of complete failures before acquiring the correct technic. The difficulty lies in the fact that the *x*-ray must penetrate the entire thickness of the head from behind forward sufficiently to act upon a photographic plate, and still be capable of sufficient selective absorption to show the differences in density at the region of the frontal sinus.

Some plates will be found not to show sufficient effect from the *x*-ray, and this may be due either to the use of too high a degree of vacuum (the rays passing right through the plate without chemic effect), to too low a degree of vacuum (the rays all being absorbed by the 7 or 8 inches of tissue), or by too weak an intensity or too short an exposure.

On the other hand, the plate may show sufficient density, but insufficient detail everywhere. This condition may occur with a long or strong exposure to a ray which has too great penetration and to which the denser parts of the head are almost as transparent as those less dense.

In this case more than in any other contrast is desirable rather than the greatest detail.

There is a tradition current at the present writing (A. D. 1914) that the best quality of *x*-ray for frontal sinus work is produced by an open core transformer. This is a question of importance, which the author is unable to decide. It means a return to the induction-coil type, but with an alternating or a polyphase primary current instead of a direct interrupted one.

Relative Positions of the Tube, Plate, and Patient's Head.—This is of the greatest importance. The tube must, of course, be in the median line at the back of the head and the plate in front.

Many radiographs show a good picture of the antrum and ethmoid cells, but scarcely anything of the frontal sinus. This may be due to the fact that the tube is in such a position that the image of the thickened mass of bone at the occipital protuberance is thrown directly upon that of the frontal sinus. Other radiographs of the accessory pneumatic sinuses of the face have the image of the ethmoid cells or antrum obscured by the shadow of the petrous portion of the temporal bone. The shadow of the horizontal plate of the frontal bone should not fall across the orbit, but just at its upper border.

The shadow of the horizontal plate of the frontal bone should not fall upon that of the frontal sinus. The shadow of the petrous portion of the temporal bone should not fall on that of the antrum, nor that of the basillar process of the occipital bone on the shadow of the ethmoid cells. There is only one position which satisfactorily avoids all defects:

The patient's forehead and nose should be pressed against the plate. The tube should be behind the head, in the median line, and along a line passing from the glabella (junction of nose and forehead) backward through a point in the skull, which is usually to be felt as a slight depression 1½ inches above the occipital protuberance.

The proper direction has also been described (Caldwell) as along a line 23 degrees above the line joining the glabella and the external auditory meatus.

The patient's forehead is pressed against the plate because this gives a clearer image of the frontal sinus than if the plate were a little further away from the forehead, as would be the case with theplate parallel with the front of the face and equidistant from the mouth and forehead.

The x-ray, after traversing the entire thickness of the head, consists partly of rays travelling in straight lines from the anticathode of the x-ray tube, and these, of course, would make a clear image if the plate were held at any reasonable distance, but there are also secondary rays which radiate in every direction from the various points where they arise. The image of the frontal sinus cast by these secondary rays might be clear enough if the plate were directly in contact with the forehead, and very much blurred if the plate were at a distance.

Fig. 642.—Radiography of the frontal sinus. The patient seated with the chin resting upon the table.

The Position of the Patient.—This is largely a matter of convenience, and different positions will be found desirable under different circumstances:

(1) The patient seated with the chin resting on the table, the plate leaning against the nose and forehead, and the tube behind (Fig. 642).

(2) The patient lying face down upon the plate; the tube over the back of the head (Fig. 643).

(3) The patient lying face up; the tube under the back of the head; the plate over the face.

(4) The patient lying on his side upon the author's lateral plate-holder, which holds the plate in front of the patient's face; the tube behind the head.

The *second* position (Fig. 643) is a very convenient one, as all it requires is that the patient shall climb upon the table and lie face down. It does not permit of a preliminary fluoroscopic examination as do the others, but this is often unnecessary and undesirable. More than half of the author's radiographs of the frontal sinus are made in this position.

The *first* position (Fig. 642) is the most pleasant one for the patient, but requires that the table shall be at the proper height or that something shall be piled upon it. There is also more danger of the patient's moving. The last difficulty may be overcome by having a block at an adjustable height, which the patient holds tightly between his teeth, and which is clamped fast to the table or to the plate-holder. This position enables one to make a preliminary fluoroscopic examination if necessary. The author sometimes uses it in the case of intelligent patients.

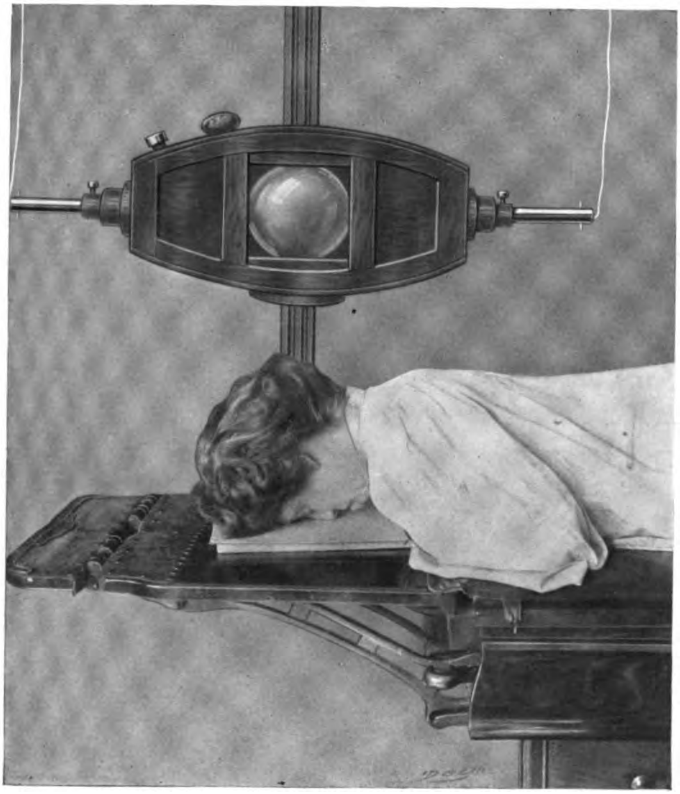

Fig. 643.—Radiography of the frontal sinus with the patient lying face down. A diaphragm or cylinder should be used.

The *third* position requires a special table or canvas stretcher, so that the patient's head may rest upon a portion transparent to the x-ray. The x-ray tube is placed under this part of the table. Those who use this position include Caldwell, who makes such radiographs exceedingly well. This position is especially adapted to the preliminary use of the fluoroscope in judging the radiographic quality of the ray.

The fluoroscopic screen is laid over the patient's face and the current turned on for an instant. If the image is seen to be a good one the current is turned off and a photographic plate substituted for the screen, the current then being turned on long enough to produce a radiograph. The most extraordinary precautions should be taken to shield the operator's face, eyes, hands, and genital organs from the x-ray if a routine use is made of this method.

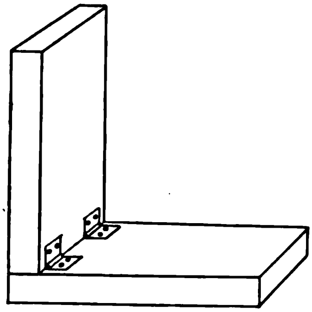

Fig. 644.—Tousey's lateral plate-holder.

The author considers this method altogether too hazardous to be recommended, as the ray that is required is one of great intensity and penetration, and the operator has to stand with his whole body very near the tube while he bends over the fluoroscope.

The *fourth* position requires the author's special apparatus, but this is of the simplest construction.

The Author's Lateral Plate-holder (Fig. 644).—This consists of a horizontal and a vertical board, hinged together in such a way that they may be folded up for packing away, but cannot open more than 90 degrees. The patient lies with the side of his head resting upon the horizontal board and with his face close to the stereoscopic plate-holder or ordinary x-ray envelope, which is held in place by the vertical board. The x-ray tube is behind the patient's head (Fig. 645). If a preliminary fluoroscopic examination (Figs. 646 and 647) is necessary, the operator is as far away from the tube as he can ever get in fluoroscopic work, and there is abundant room for the use of protective screens.

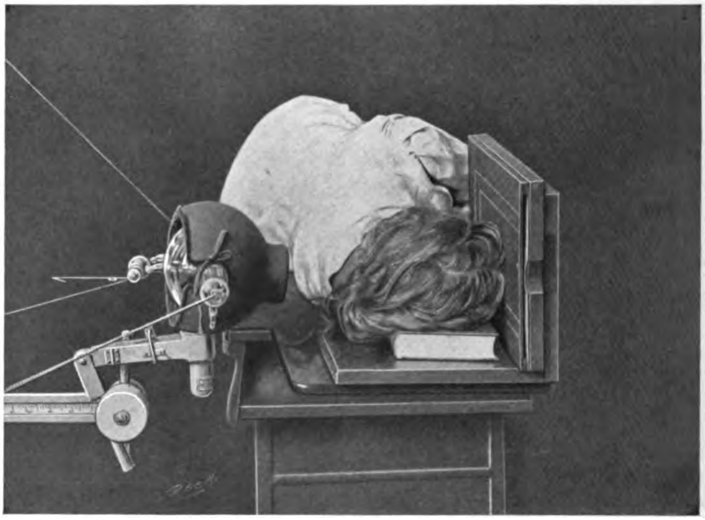

Fig. 645.—Radiography of the frontal sinus, employing the author's lateral plate-holder.

A fluorescent screen may be placed on the further side of the author's lateral plate-holder. The operator, standing behind a protective screen of sheet-lead and lead-glass in a completely darkened room and regarding the fluoroscopic screen in a mirror so as not to be in a line with the direct rays, can observe the fluorescence produced in the screen by rays passing through the patient's head. The moment the image of the orbits becomes vague the current should be turned off. It indicates that the vacuum has become too high or too low, and every second of exposure under these circumstances is only blurring the image already on the plate. It may be that practically a sufficient exposure has already been given, and in that case the picture is regarded as finished. Additional exposure may

Fig. 646.—Fluoroscopy of the frontal sinus preliminary to radiography with the author's lateral plate-holder. This position is exceedingly dangerous to the operator. (See text for precautions required.)

Fig. 647.—Diagrammatic representation of fluoroscopic examination of frontal sinus. This position is exceedingly dangerous to the operator. (See text for precautions required.)

be given if required after the tube has been regulated or another has been substituted for it. The position of the anticathode should be exactly the same. An additional reason for recognizing the fact that the radiance is no longer of a character to produce one of these difficult pictures lies in the fact that continued exposure is using up the comparatively few seconds' exposure that the scalp should be subjected to. Every second ought to add to the clearness and depth of the picture. Not a second of useless exposure should be given.

Care should be taken that the median plane of the patient's head is horizontal. A little pad may be placed under the side of the neck.

As the antrum is also included in the picture, it is the author's custom to have the patient hold a cork between his teeth. The landmarks of the upper jaw are clearer if the mouth is open.

Allusion has been made to the stereoscopic plate-holder. It is seldom necessary to make a stereoscopic radiograph in frontal sinus cases, but it is sometimes desirable to change the plate if we suspect that the patient has moved, or if the tube has undergone some notable change, or simply if one wishes to take two separate pictures in the hope that a slight difference in all the conditions will result in one picture being better than the other. The stereoscopic plate-holder enables one to remove the first plate and put another in exactly the same position without moving the patient or any part of the apparatus.

The author's lateral plate-holder enables one to dispense with a stereoscopic plate-holder. In that case it is necessary to have cardboard or paraffin paper over the regular *x*-ray envelopes to protect the plates from the moisture of the breath and perspiration.

The Distance from the Tube to the Plate.—The selection of the distance is influenced by two consideratons: first, that a short distance will give a better picture and in a shorter time than a long distance; and, second, that too close proximity to the back of the head with so long and strong an exposure may produce alopecia or dermatitis—18 to 21 inches will be found to be the best distance.

Caldwell[1] uses a distance of 18 inches from anticathode to plate and an exposure of twenty seconds. His article does not state what interrupter he uses, but it is supposed to be a Caldwell. "With a certain interrupter and coil, with the rheostat resistance all out, a reading of 10 milliamperes shows that the penetration of the tube is about high enough" (Caldwell).

The Technic of the Exposure.—The author's rule is to use a quality and intensity of *x*-ray and a length of application which he finds gives the best result in making a renal calculus picture in a large patient. He is apt, therefore, to use a current of 15 to 18 amperes with an induction-coil and electrolytic interrupter and to give an exposure of one minute or thirty seconds. It requires the best technic to make such a picture with an unfluctuating converter or a transformer in one second or less. The exposure is sometimes divided up with intervals of cooling, so as to maintain the best degree of vacuum. A change in the degree of vacuum means a poorer picture in the same length of time or an increased exposure of the patient for an equally good picture.

These pictures present such difficulty that the author will repeat here some of the general details as to technic which have already been described elsewhere.

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[1] Am. Quarterly of Röntgenology, Jan., 1907.

With a 12-inch induction-coil with a Caldwell or a Wehnelt interrupter, and a rheostat in which the resistance is afforded by different strips of metal, the interrupter is regulated to give a current of 11 amperes with the Caldwell or 15 to 22 amperes with the Wehnelt interrupter, and some resistance is used while the vacuum of the x-ray tube is regulated to the proper degree. This should be such a degree that with all the rheostat resistance cut out the tube will back up a parallel spark of 5 or 6 inches. The milliamperemeter should indicate the passage of 8 or 10 milliamperes of secondary current through the tube. The penetration of the ray should be about 8 Benoist.

The use of an unfluctuating converter or of a transformer permits of a current of about 90,000 volts and about 50 milliamperes as the best routine factors for this work.

The tube should have a *penetration of No. 6 or 8 Benoist.*

The Diaphragm.—This is absolutely essential. A cylinder diaphragm may be used or the author's contact diaphragm (p. 761).

The *plate* should be as rapid as possible. Such a plate as the Lumiere Sigma plate is suitable. It is approximately four times as rapid as most plates made in this country. The Ilford is another fine imported plate. The paragon screen plate gives good results with an intensifying screen if care is taken to avoid overexposure.

The Time of Exposure.—This varies from a fraction of a second to fifteen or sixty seconds, according to the apparatus and the quantity of power employed. A transformer is considered good which will make a frontal sinus picture in a second without an intensifying screen. It would have to be about the same as to produce an abdominal or hip-joint radiograph.

It would be a very serious mistake for an operator with a powerful apparatus to try to overcome errors in technic or relative position by giving long exposures. There would be danger of dermatitis or alopecia.

A metal tube passed up through the infundibulum has shown very well in a lateral radiograph by the author; not quite so well in an anteroposterior one.

The plate shows very much better than the print in all radiographs of the accessory pneumatic sinuses taken in an anteroposterior direction. It is to be examined in a perfectly dark room by means of a negative examining box. The latter has a framework which receives the plate, behind which is a sheet of opal glass lighted by a number of incandescent lamps. The degree of illumination is regulated by a rheostat. The most brilliant light does not always show the picture to the greatest advantage.

In the absence of a negative examining box such a plate may be studied in a darkened room. The plate is held up between the observer and a sheet of white paper, upon which a fairly brilliant light is thrown. These plates are usually not strong enough to show well if held up in front of an ordinary electric light.

The plate may be treated, as suggested by Caldwell, to accentuate the important portion of the image. A square of sheet lead, together with lead numbers and lead letters spelling the words *right* and *left*, is placed over the central part of the plate after the exposure is complete and the plate removed from the patient. A convenient plan is to have all these permanently mounted on a cardboard 8×10 inches, and simply have to change the serial number of the plate each time. This contrivance being in place, a short strong exposure of a few seconds is made. As the plate is being developed this fully exposed border comes up and materially assists in the observation of the process of development by the ruby light in the dark room. The dense black border produced on the finished plate brings out the useful part of the image more clearly when the plate is examined by transmitted light.

A radiograph of a probe in the frontal sinus is considered by Douglass the only certain proof of its entry into the sinus.[1]

Jack, at the time of reading his article,[2] regarded the value of the *x*-ray in frontal sinus diagnosis as still *sub judice.* Radiographs made for him had not proved successful.

Mosher[3] reports the successful employment of the radiographic method of examination in sinus disease.

Harland and Pancoast believed, at the time of reading their report at the Annual Meeting of the Medical Society of the State of Pennsylvania, Sept., 1906, that a high degree of vacuum and very great electric power were required. They used an induction-coil with 60 amperes of current through the primary coil, a distance of 16 inches from the anticathode to the plate, and an exposure of ten to twenty seconds. This is a tremendously powerful current. They made their pictures with the tube below the level of the occiput. They used a diaphragm.

Cryer's dissections of the frontal sinus[4] show a very great diversity in frontal sinuses which have been free from disease. Some are very small, while others spread all over the forehead and temples. Some have as many as five or six separate pockets with a number of separate outlets. Such variations would be discoverable by anteroposterior radiograph.

Figs. 648 and 649 show variations in the normal appearance in cases in which the author has made radiographic examinations of the frontal sinus.

Fig. 656 shows the frontal sinus in an empty skull used for purposes of demonstration.

Transillumination of the Frontal Sinus.—This must be done in a very dark room. A 3 candle-power incandescent lamp is enclosed in an opaque cylinder, whose open end is pressed close against the under surface of the upper wall of the orbit. A red glow may be seen defining the extent of the frontal sinus. The glow may be lessened when the sinus is filled with solid or liquid substances instead of air. The diagnostic value of the method is impaired by the fact that some sinuses, containing pus or swollen or polypoid mucous membrane, show apparently normal illumination, and others, which are perfectly normal, do not illuminate as well as usually. Sometimes in a normal case the two sides show unequal illumination.

Radiography of the Antrum or Superior Maxillary Sinus.—This accessory pneumatic sinus may be examined by the *x*-ray, either fluoroscopically or radiographically, from several different directions.

(1) The tube may be at the affected side of the face, and the fluoroscope or photographic film may be held inside the mouth, either in a

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[1] New York Med. Jour., March 10, 1906.
[2] Jour. Am. Med. Assoc., July 21, 1906.
[3] The Laryngoscope, Feb., 1906.
[4] Jour. Am. Med. Assoc., Jan. 26, 1907.

horizontal position or applied as closely as possible to the inner surface of the gums and roof of the mouth. The image shows whether the antrum is of normal size, whether it is filled with pus, polypoid, or tumor tissue, and whether any of the teeth project into it and cause trouble. The details of this examination are explained in the section on *X*-ray in Dentistry.

Fig. 648.—Normal frontal sinus (*a*) in a patient examined for frontal sinusitis; *b* and *d* ethmoid cells; *c* and *e*, antra.

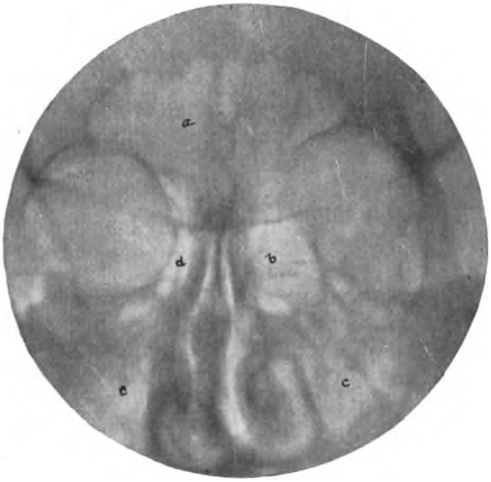

Fig. 649.—Normal frontal sinus (*a*) in a patient examined for frontal sinusitis; *b*, right ethmoid cells appear larger than left because face was turned a little; *c* and *e*, antra.

(2) The tube may be at the opposite side of the face, the mouth open, and the ray shining through the mouth from below the level of the opposite teeth, and having to penetrate only the roof of the mouth and

the upper jaw on the affected side. The fluoroscope or photographic plate is held against the outside of the face on the affected side. A comparison between the two antra may be thus obtained. The quality of the ray required is about No. 6 Benoist. A much greater degree of penetration does not afford sufficient shadow to even make out the roots of the teeth clearly with the fluoroscope. With an intensity of $\frac{1}{10}$ *Tousey* and a distance of 15 inches from the anticathode to the plate the exposure for a radiograph would be about ten seconds. The above degree of intensity is obtained with an induction-coil and a primary current of 18 amperes or another apparatus with equal power. Transformers greatly reduce the exposure.

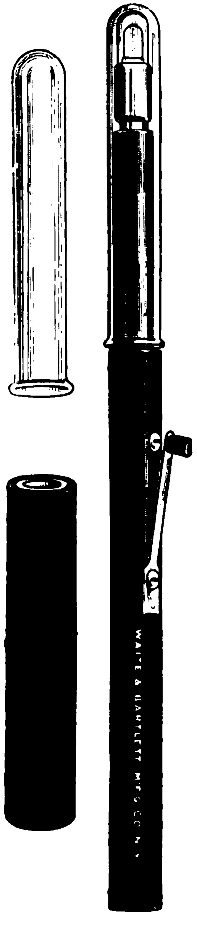

Fig. 650. — Coakley's transilluminator.

(3) The tube may be at the opposite side of the face, in a line passing through both antra from side to side. The plate is against the affected side of the face. This position is very easily maintained by the patient if he lies on the table with the plate under the affected side of the face and the tube over the opposite side. The distance should be about 9 inches, the penetration about No. 8 Benoist, the intensity $\frac{1}{10}$ Tousey, and the exposure about fifteen seconds. The above intensity may be obtained from an induction-coil and a primary current of 18 amperes. A transformer permits of exposures of from one to seven seconds.

Fig. 651 shows the antrum forming the natural air-space above the level of the hard palate and crossed vertically by the malar prominence.

Fig. 652 enabled the author to make a diagnosis of suppuration in the antrum. The case is further figured on page 904.

A radiograph made in this position does not give a comparative picture of the two sides. An important fact is that the shadow of an opaque substance in either antrum would be cast upon the plate, no matter whether it was on the side next to the plate or not. Generally it is only one side that is affected and no doubt exists as to which side. The shadow of the opposite antrum if normal offers no real difficulty, even though it is superimposed on the image of the affected side. The latter is clearer and of the natural size, while the former is enlarged and vague because of its distance from the plate. It is to secure the last condition that the tube is placed as close as practicable to the unaffected side of the face. Fig. 653 is such a radiograph of the antrum in an empty skull. Placing the x-ray tube somewhat further back enables us to secure separate images of the two antra in a lateral radiograph.

Cases occur in which it is necessary to make a comparative picture of the two antra, and then the following method is generally used:

(4) The tube is behind the patient's head and in the median line, the plate being in front. The relative position recommended for ex-

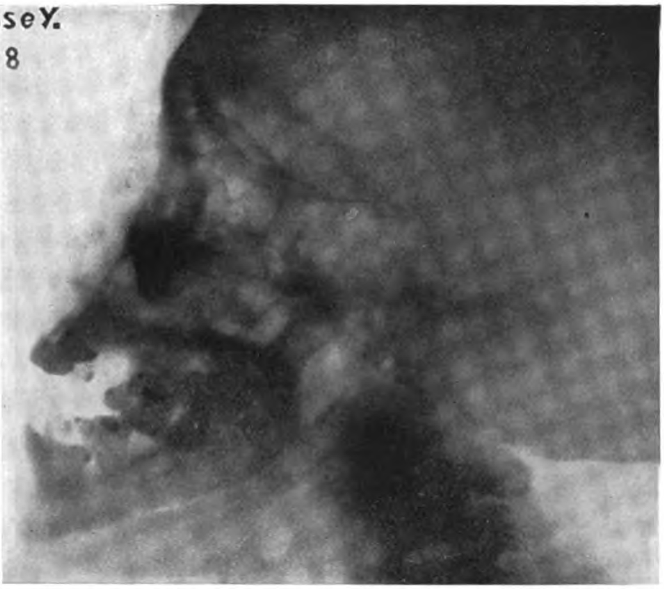

Fig. 651.—Normal antrum

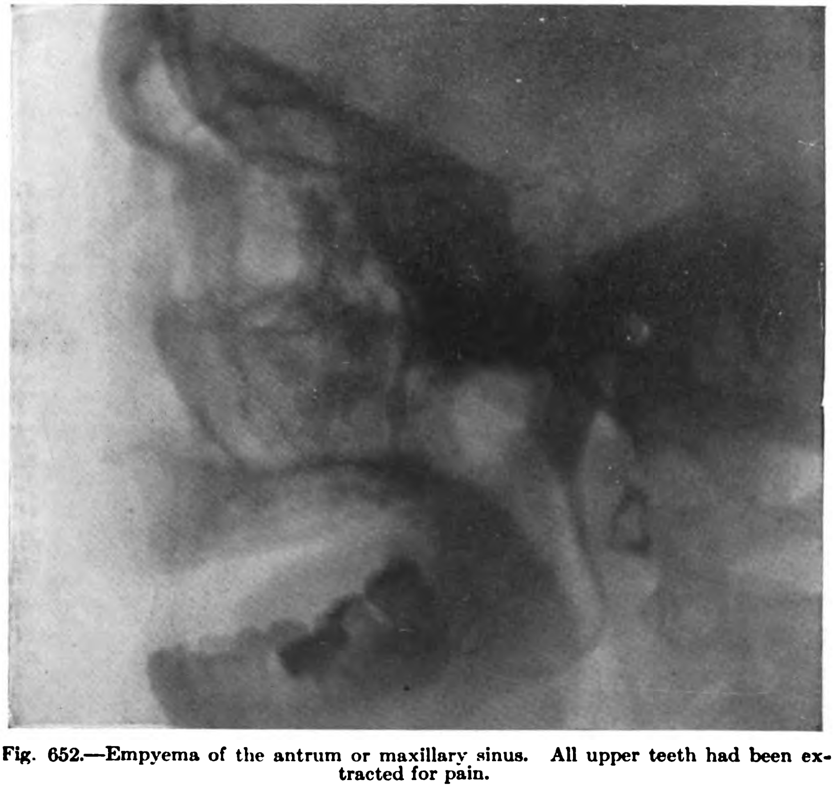

Fig. 652.—Empyema of the antrum or maxillary sinus. All upper teeth had been extracted for pain.

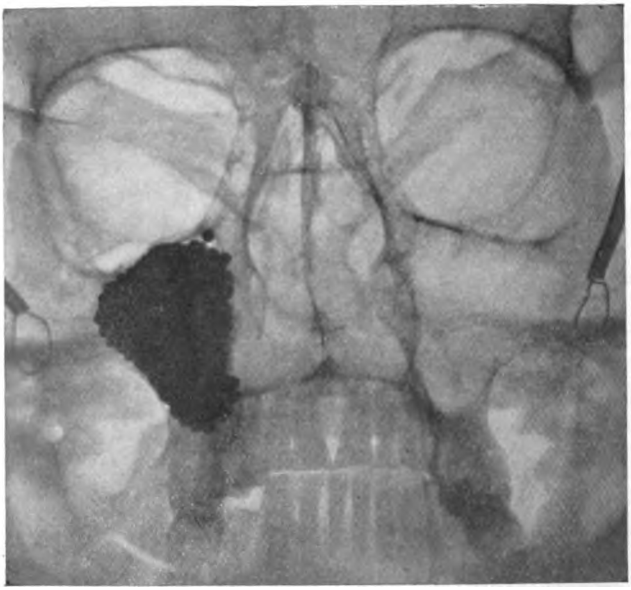

Fig. 653.—Normal antrum in empty skull (filled with shot on one side).

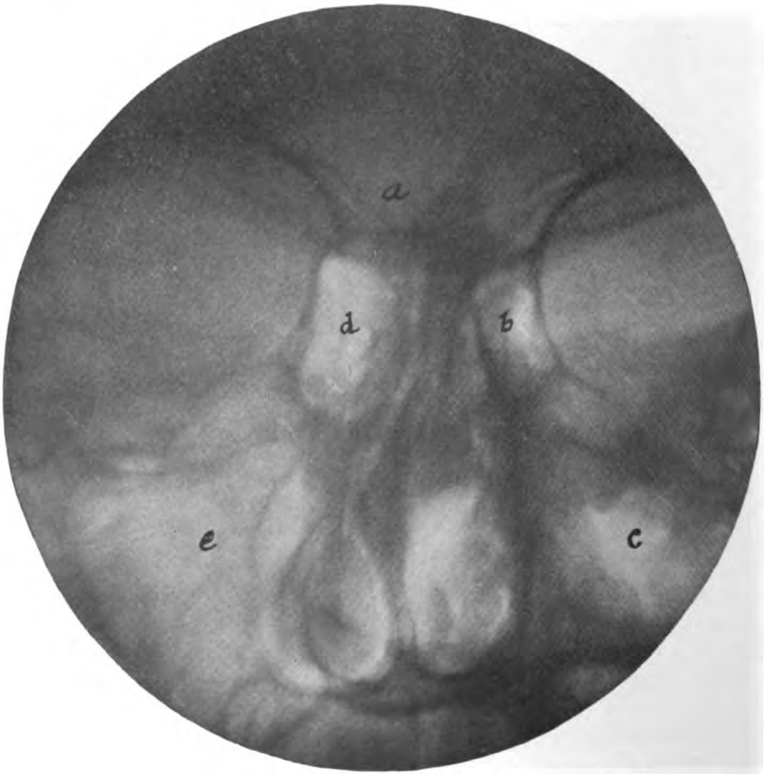

Fig. 654.—Suppuration of antrum (*c*): *a*, Normal frontal sinus; *b* and *d*, normal ethmoid cells; *c*, normal antrum.

amination of the frontal sinus answers very well for the antra. The frontal sinus, ethmoid cells, and both antra often show very well on the same plate. The antra alone are somewhat better shown in a radiograph made with the chin somewhat flexed toward the chest and with the tube at such a level that the shadow of the occiput falls above the antrum. The antra show better when the tip of the nose is pressed right against the plate than when the forehead touches the plate.

This position may be obtained in any of the ways mentioned on pages 894 to 897 in describing anteroposterior radiography of the frontal sinus. One of the best being with the author's lateral plate-holder, the patient lying on his side; and the other with the patient lying face down upon the plate.

This picture is less difficult than the anteroposterior one of the frontal sinus, but at the same time is far from easy. The best degree of penetration is No. 7 Benoist, and the exposure should be thirty to sixty seconds, at a distance of 18 inches from the anticathode to the plate, with an intensity of No. $\frac{1}{8}$ or $\frac{1}{4}$ Tousey.

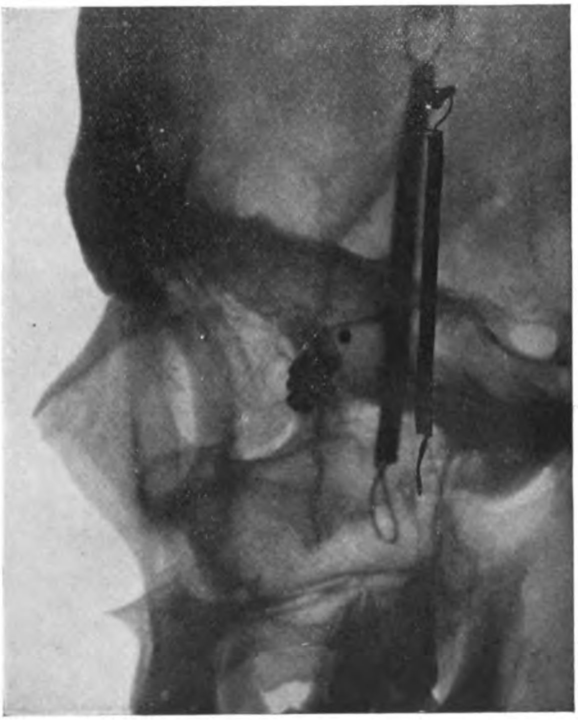

Fig. 655.—Middle ethmoid cells full of lead. Lateral view.

Fig. 654 shows a case of long-standing suppuration in the antrum; the same patient as Fig. 652.

Radiography of the Ethmoid Cells.—The ethmoid cells lie between the inner walls of the two orbits and the upper parts of the nasal fossæ.

The anterior ethmoid cells show in either an anteroposterior or a lateral radiograph. The posterior ethmoid cells can be studied best in a lateral radiograph. Figs. 655 and 656 show the position of the middle ethmoid cells in an empty skull.

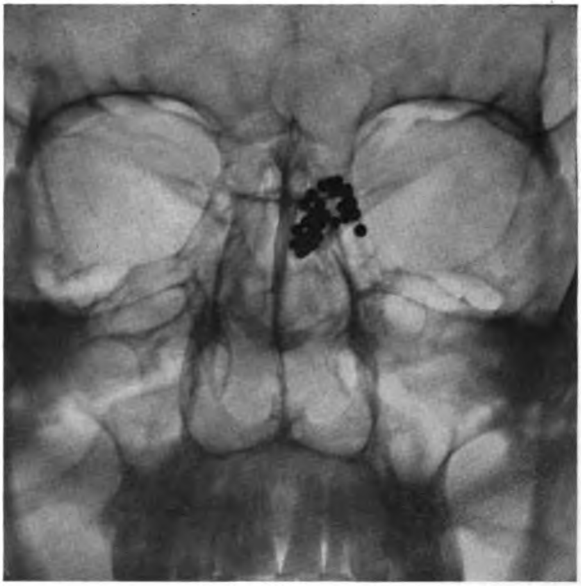

Fig. 656.—Middle ethmoid cells full of lead. Frontal sinus and antrum in natural condition. Anteroposterior view.

Fig. 657.—Chronic suppuration in antrum and ethmoid cells. Radiograph made with the tube at a much lower level than the occiput. This is practicable only for the antrum. The base of the skull obscures the frontal sinus.

The anteroposterior examination is made with the plate in front. The tube is behind the head, and may be above the occiput at the same level as in radiography of the frontal sinus or below the level of the occiput, as in one of the positions for the antrum. The choice of position will depend upon whether the involvement is supposed to extend to the frontal sinus or to the antrum. The *x*-ray should be of a penetration of No. 8 Benoist; with an intensity of $\frac{1}{14}$, the exposure should be one or two minutes at a distance of 18 inches. With an intensity of $\frac{1}{10}$ Tousey and a primary current of 18 amperes the exposure should be fifteen to thirty seconds. An exposure of one to seven seconds is usual with a transformer.

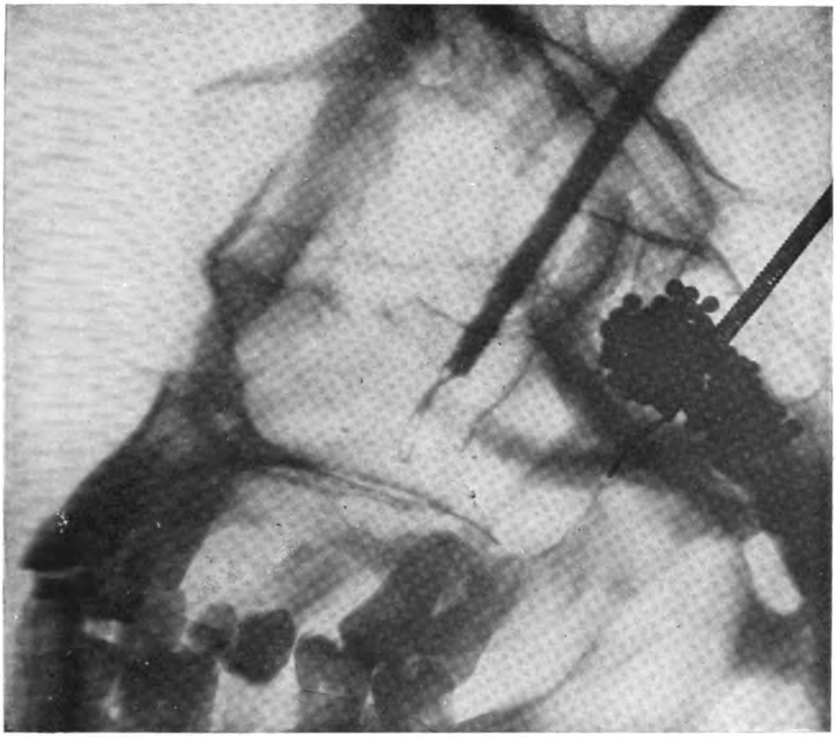

Fig. 658.—Lateral radiograph of the sphenoid cells full of lead in an empty skull.

Fig. 657 is a radiograph of a young lady with long chronic suppuration in the antrum and ethmoid cells, as evidenced by the dark tract on one side.

The lateral view of the anterior or posterior ethmoid cells is not a difficult radiograph to make. The patient may lie with the affected side of his face resting upon the plate. The tube is over the other side, at a distance of 13 inches from the anticathode to the plate. The penetration should be No. 7 Benoist. An intensity of $\frac{1}{14}$ Tousey will require an exposure of forty-five to sixty seconds. An intensity of $\frac{1}{10}$ Tousey with a primary current of 18 amperes will require an exposure of fifteen to thirty seconds. One to seven seconds suffice with a transformer.

Radiography of the Sphenoid Cells.—These are studied in a lateral radiograph made in the same manner as that of the ethmoid cells.

Figs. 658 and 659 are radiographs made of the sphenoid cells in an empty skull. They show the relation of these cells to the normal lights and shadows of the adjacent parts. They have served the author as anatomic charts.

In a radiograph of an actual patient a certain dark shadow was seen to correspond with a natural bony shadow in the chart and not with the position of the air-space forming the sphenoid sinus. The conclusion was that this sinus was not filled with pus.

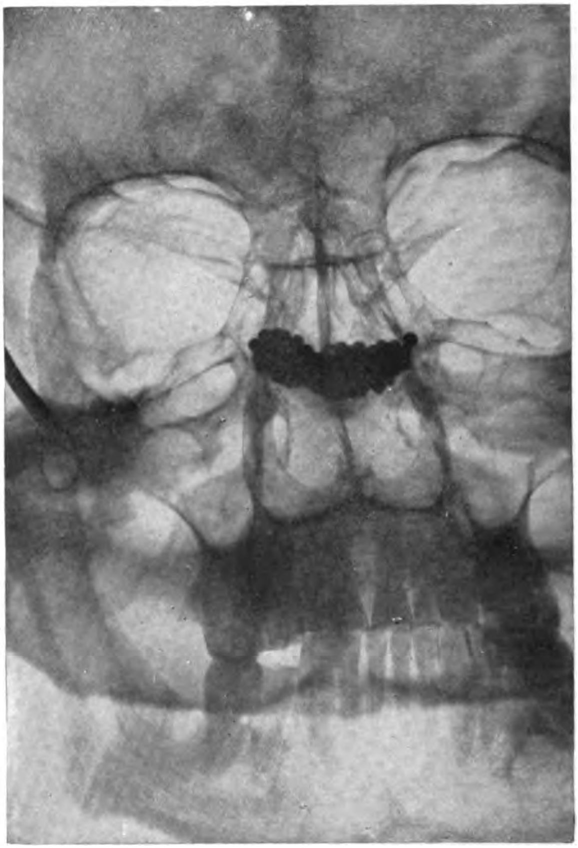

Fig. 659.—Anteroposterior radiograph of the sphenoid cells full of lead in empty skull.

Stereoscopic Radiographs of the Pneumatic Sinuses of the Face.—Stereoscopic radiographs of the sinuses may be made by having the tube 1½ inches to one side of the median line for the first plate, and the same distance to the other side for the second plate.

The anteroposterior radiographs of the frontal sinus require so long and strong an exposure that the double length of exposure required for stereodiagraphy is usually undesirable.

There is not the same objection to the stereoscopic method in lateral radiographs of the frontal sinus, the ethmoid cells, and the antrum.

The Turbinated Bones and Septum Nasi.—The turbinates show in any of the anteroposterior radiographs of the face. Their size and shape are shown and the extent to which they encroach upon the nasal passages. Deviations or old or recent fractures of the septum are well shown.

Topography of the Pneumatic Sinuses of the Face as Shown in Radiographs.—The author exhibited at a meeting of the Rhinological and Laryngological Section of the N. Y. Academy of Medicine, November, 1907, a series of radiographs of an empty skull in which one or other of the sinuses was filled with lead shot. The radiographs were made in either a lateral or an anteroposterior direction and some of them were stereoscopic. The value of such pictures lies in the guide which they afford to the recognition of the different sinuses in radiographs made from actual patients.

Some of these radiographs are reproduced in Figs. 655, 656, 658, and 659.

THE NECK

Fluoroscopic examination of the neck is rather inconvenient, but would reveal the presence of foreign bodies or tumors. Fractures of the vertebræ and pathologic changes in the larynx are much better studied in the radiograph. There is a case on record of the image of the cartilages of the larynx being mistaken for a set of false teeth—operation, death, teeth not found in the patient's throat, but subsequently discovered in his bed.

Lateral Radiography of the Neck.—In radiographing the neck from the side the patient is sitting up, the plate is at one side of the neck and parallel with the median plane of the body, the chin is somewhat elevated, so that the body of the jaw is horizontal. The tube is on the opposite side, at a distance of 20 inches from the anticathode to the plate, and about half an inch below the level of the chin. The resistance may be from 2 to 4 inches and the penetration from No. 6 Benoist, exposure one minute with 10 amperes (intensity $\frac{1}{18}$ Tousey), or thirty seconds with 15 amperes ($\frac{1}{14}$ Tousey). Transformers reduce the exposure to one to seven seconds. It may very well be found that the plate will show details which it will be difficult to bring out in the print. The picture shows the lower jaw, the tongue, the esophagus and pharynx, the hyoid bone, the cartilages of the larynx, the cervical vertebræ, and sometimes the styloid process of the temporal bone. An unusual amount of ossification in the thyroid cartilage is said to have caused it to be mistaken for a set of false teeth in the case referred to above.

An **anteroposterior radiograph** of the neck is made with the patient lying face up on the table, with the plate under the back of the neck, and the tube vertically over the cricoid cartilage. The distance is 18 inches from the anticathode to the plate, the penetration about No. 7 Benoist; an intensity of about $\frac{1}{14}$ Tousey requires an exposure of from forty to seventy-five seconds, depending upon the size of the patient. Transformers producing $\frac{1}{6}$ to 1 Tousey power reduce the exposure to one to seven seconds, with about 70,000 volts and 20 to 50 ma. Fig. 660 is of a patient whose larynx had been removed for carcinoma; the tracheotomy tube is shown.

Cervical Ribs.—The anteroposterior position is the correct one for an examination for this condition. The distinctive appearance in this case is the fact that such a supernumerary rib does not extend around to the front of the neck, but forms a short straight bone. A good radiograph is required to differentiate a cervical rib from the transverse process of a vertebra. Where it is quite rudimentary, however, it is usually not the cause of the symptoms complained of.

The affection is more often bilateral, arising from the seventh cervical vertebra, but one supernumerary rib may be more developed than the other. It may be merely rudimentary or present any form between this and a fully developed rib. The effects are serious when the vessels and nerves pass over it. The symptoms as summarized by Keen[1] are: 1, There may be a hard tumor in the neck with a high and obliquely pulsating subclavian artery; 2, there may be severe neuralgic pain, perverted sensation, and hoarseness; 3, there may be thrombosis in the subclavian artery, gangrene and edema of the extremity, and a suggestion of aneurysm; 4, there may be wasting of the muscles of the arm, dysphagia, and scoliosis.

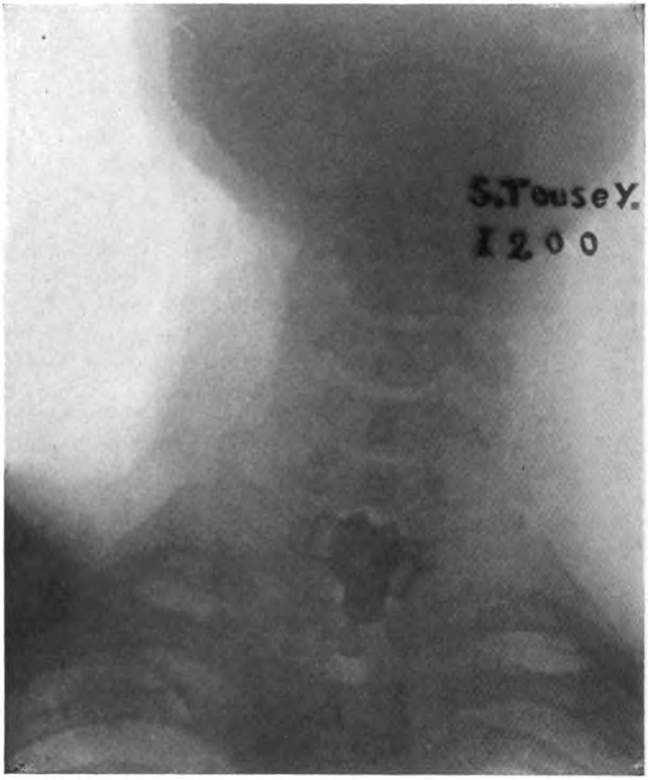

Fig. 660.—Anteroposterior radiograph of the neck. Tracheotomy tube in position after laryngectomy for carcinoma.

Rotary Dislocation of the Atlas.—This comparatively rare, but not

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[1] Am. Jour. Med. Sciences, Feb., 1907.

necessarily fatal injury may be diagnosticated by a lateral radiograph of the neck.[1]

Forward Dislocation of the Atlas.—Forward dislocation of the atlas with fracture of the odontoid process of the axis is the lesion which the legal hangman aims to produce, and which usually occasions such compression or laceration of the spinal cord as to cause practically instant death. A lateral radiograph of the neck demonstrates it.[2]

Fracture of the Cervical Vertebræ.—This will show in an anteroposterior radiograph, but a lateral one will usually be found more desirable.

Localization of Foreign Bodies in the Tissues of the Neck.—Stereoscopic radiography, either lateral or anteroposterior, gives interesting results in localizing such foreign bodies as bullets.

Localization on the McKenzie-Davidson principle is valuable in the same class of cases.

It is much simpler, however, to take two radiographs of this region at a right angle, first fastening a lead marker on a part of the neck where its image will not cover that of the bullet which is located in this way. The same thing may be accomplished with the fluoroscope. The neck is examined at first from the side, and a lead marker is applied at each side of the neck in a direct line with the bullet, as seen in the fluoroscope. Then the fluoroscope is held behind the neck and the tube in front while another pair of markers are applied. The intersection of these two lines is readily found by the surgeon if the different marks are made durable by nitrate of silver.

Localization of Foreign Bodies in the Esophagus.—These are very apt to be metallic, and if of considerable size, like a coin, should be easily located in any part of the esophagus. One glance at the fluoroscope will generally reveal the presence and position of the foreign body. This was the case in the author's own patient, whose radiograph (Fig. 661) was taken simply as a record. The nickel five-cent piece was removed by a coin-catcher passed down through the mouth without waiting for the photographic plate to be developed. A good deal of twisting and pulling was required in this case, as the coin had been in position for nine days and had begun to ulcerate through the wall of the esophagus. The utmost gentleness had to be used in these manipulations, and it required five minutes to remove it after it was engaged in the coin-catcher. This instrument, it will be remembered, is a sort of blunt hook hinged upon a flexible handle, and is passed beyond the coin and then withdrawn. When it engages the coin, the latter is brought out by pressure applied at its most distal part, and the coin may tip in one direction and tear the wall of the esophagus if it catches in a depression caused by ulceration. Such an accident is to be avoided by gentleness and by twisting and turning. If the coin refuses to move the coin-catcher should be freed from it by pushing it back and then turning it into a position in which it slips past the coin and out of the patient's mouth.

The next step in such a case would be one which might have been used in the beginning—extraction by forceps under fluoroscopic observation.

[1] Corner, Annals of Surgery, Jan., 1907.

[2] Kelly, Ibid., August, 1905.

The position of the coin is first ascertained by the fluoroscope and the esophageal forceps are then introduced. Again the fluoroscope is used, and the coin seized by the blades of the forceps under direct observation. Traction is then made, and as it is exerted upon the proximal part of the coin the latter has no tendency to hook into the esophageal wall. Henrard[1] has devised special forceps for this particular case.

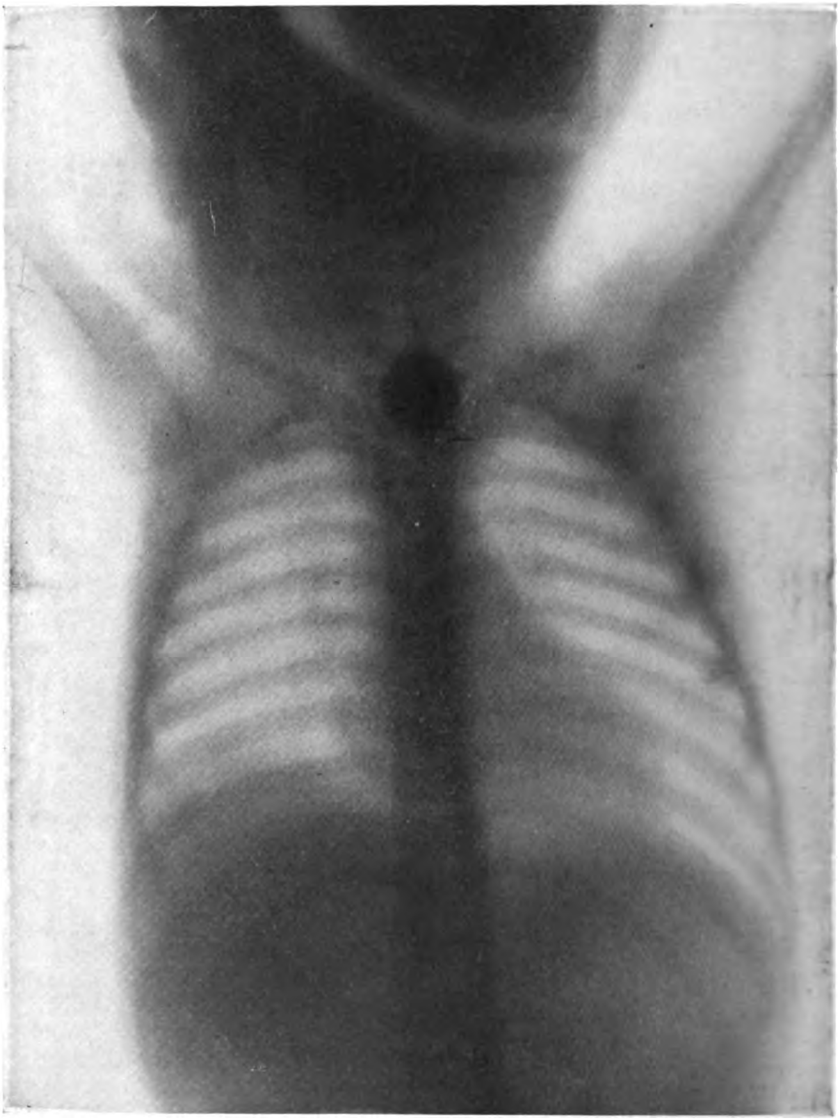

Fig. 661.—Coin lodged in esophagus of a child three years old.

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[1] Le Radium, Sept. 15, 1905, p. 302.

No harm is usually done if a coin lodged in the esophagus is pushed into the stomach in the course of efforts at extraction.

If a coin or any other foreign body cannot be detected by the fluoroscope a radiograph should be made and developed at once.

A coin or other foreign body which has been located in the esophagus by an *x*-ray examination, and which has resisted efforts at extraction through the mouth or dislodgment into the stomach, usually requires esophagotomy. This is so serious an operation that the radiologist should guard against every possible source of error in making his diagnosis of the presence of a foreign body from the *x*-ray appearance.

A most striking case in this connection was that of a patient who was supposed to have swallowed a set of false teeth. The radiologist thought he could see them and an esophagotomy was performed. They were not to be found in the patient's esophagus. The patient died from the operation, and the false teeth were discovered under the pillow in his bed. The explanation given was that some part of the larynx was unnaturally dense, and that its shadow had been mistaken for that of a foreign body. The hyoid bone, especially its cornu in a lateral view, presents a shadow which might be mistaken for a foreign body, a misplaced tooth, or a salivary calculus.

Needles or pins are sometimes easily detected and sometimes do not show. A case of this kind which the present author examined was that of a circus performer and sword swallower. He was in the habit of swallowing needles, which were probably caught in some kind of receptacle out of sight in the esophagus. After the performance this receptacle was to be pulled up out of the man's throat. On a certain occasion some of the needles were supposed to be missing, and a few days later the author made a radiograph of the thorax, which did not reveal them.

Fish bones and small chicken bones would usually not show in a radiograph of the thorax; they might if lodged in the throat.

Rectenwald[1] removed a silver quarter dollar located by the *x*-ray (radiograph by Johnston) 219 days after lodgment in the esophagus.

Hannecart[2] located a hard-rubber dental plate which had been allowed to remain in the esophagus for ten days, the medical attendant having been deceived by the fact that an esophageal sound could be passed without obstruction. Esophagotomy was successfully performed. The foreign body had caused a peri-esophageal abscess and a necrotic condition of the wall of the esophagus, but no dyspnea.

Scannell[3] reports a case of *x*-ray localization of a foreign body lodged in the esophagus for seven weeks. It was successfully removed.

King[4] located a child's tin-whistle lodged in the esophagus for ten days. Esophagotomy was successful.

A pin hidden in one of the ventricles of the larynx would be readily shown by a lateral radiograph, though undiscoverable by the laryngoscope. Mackintosh and Downie have reported such cases. The author knows of a case in his own family where a pin escaped detection by the laryngoscope and caused cough, persisting for two years. It was

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[1] New York Med. Jour., Jan. 13, 1906.
[2] La Revue de Stomatologie, May, 1905.
[3] Boston Med. and Surg. Jour., Dec. 27, 1906.
[4] Medical Record, Oct. 27, 1907.

finally dislodged by a fit of coughing. The x-ray, if it had been known at that time, would probably have discovered it.

Other foreign bodies, such as pins and metal washers, have been located in the esophagus by means of the x-ray and successfully removed.[1]

Stricture of the Esophagus.—The x-ray study of this condition may be done by the use of a flexible bougie with a metallic olive-shaped extremity, or, according to a suggestion by Chandler,[2] two such olivary bougies may be used. One may be pushed through the stricture and then withdrawn until it engages behind it, the other being pushed down to the face of the stricture. The radiograph would show the position of the two olivary tips and the distance between them. An anteroposterior picture is made with the plate behind, and using the same technic as in other neck or chest radiographs, according to which region of the esophagus is affected.

There is everything to be gained by fluoroscopy during the extraction of a foreign body from the esophagus, provided that one is exceedingly careful to prevent overexposure. The patient should lie face up on a canvas or thin wood table, with the x-ray tube underneath. The room is entirely darkened, and the image of the foreign body and the forceps or coin-catcher are observed upon an open fluoroscopic screen laid over the patient's neck and chest. The danger to the operator would be very great if such cases occurred frequently.

The x-Ray Diagnosis of Diverticula or Stenosis of the Esophagus.—This is made by means of radiographs taken after a patient has swallowed an emulsion of bismuth, or a paste made of potato and bismuth, which shows perfectly black in the location at which its progress is arrested.

The bismuth or iron emulsion for radiography of the esophagus should form a thick liquid.

A thick paste of mashed potato and bismuth or iron is preferable to the liquid for radiographic purposes.

The proper position is that the patient lie flat upon his back on the plate, with the tube vertically over the portion of the esophagus which is suspected to be the seat of the lesion.

Spindle-shaped Dilatation of the Esophagus.—This condition has been diagnosed by Sjögren[3] in 2 cases. One patient was fourteen months old, and was given three or four teaspoonfuls of an emulsion containing 8 grams of bismuth subnitrate. A lateral radiograph showed the esophagus as a narrow ribbon (visible because of adherence of particles of bismuth) down to the level of the eighth dorsal vertebra. There the shadow became large and dense in a spindle shape. An anteroposterior radiograph showed the spindle-shaped mass, but not the traces of bismuth in the upper part of the esophagus. The other patient, a man of thirty-seven years, was given 60 cc. of an emulsion containing 25 grams of bismuth subnitrate. A lateral radiograph showed a spindle-shaped shadow beginning at the level of the seventh dorsal vertebra. The dorsal radiograph showed everything but the upper end of the shadow where it was overlapped by the heart and vertebræ.

Stenosis of the Esophagus Due to Pressure by Mediastinal Tu-

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[1] Black, Amer. Med. Jour., Jan. 28, 1905.

[2] New York Med. Jour., Jan. 13, 1906.

[3] Fort. auf. d. Gebeite d. Roent., vol. x, No. 5, p. 270, Dec. 24, 1906.

mors.—Two cases of this nature were diagnosticated by Barba[1] from x-ray examinations, aided by the passage of a sound filled with a concentrated mixture of bismuth subnitrate or provided with a metal stylet.

Retropharyngeal Abscess.—This is a condition the diagnosis of which may be assisted by a lateral radiograph of the neck. A clearly defined area with its convexity forward is traced behind the tract of the esophagus and of the larynx or trachea, but without marked difference in density from the surrounding tissues.

A Tumor of the Neck is Diagnosed in a Similar Way.—Generally speaking, the differential diagnosis between a tumor and an abscess in the neck by means of the x-ray is not so much a difference of density as in the shape and position of the tumor.

Fig. 769, p. 1117, is a radiograph taken of a patient under treatment for recurrent carcinoma of the neck. The original growth was in the larynx, and a complete laryngectomy had been performed about a year before this picture was made. There was a recurrence of the cancerous growth in the tissues of the neck, forming at the time that he came under treatment a mass about the size of a small apple, and occupying the position from which the larynx had been removed. The patient was still able to breathe through a tracheotomy tube, but the growth had completely obstructed the esophagus. The results of x-ray treatment in this case are described in the chapter on "The Therapeutic Use of the x-Ray." The picture shows this growth as a portion of the tissue, not differing in density very much from the other solid tissues of the neck. It shows the air-space of the trachea terminating suddenly at the level of the growth. No trace of the original cartilages of the larynx is to be seen.

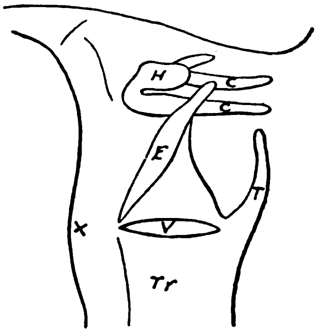

Fig. 662.—Diagram of appearance of the larynx in a lateral radiograph. *H*, Body of hyoid bone; *CC*, cornua of hyoid bone; *E*, epiglottis; *T*, upper cornua of thyroid cartilage; *X*, prominence of larynx; *Tr*, trachea; *V*, ventricle of larynx (after Grasberg).

Radiographic Diagnosis of Laryngeal Lesions.—It is very important to have a radiograph of the normal larynx taken with one's own apparatus and technic as a means of comparison. A chart showing the location of the different cartilages and other parts of this section of the neck is given in Fig. 662. The radiograph itself should be a lateral one, with a small plate held as closely as possible to the side of the neck, and with the anticathode at a considerable distance, say 15 inches, from the plate. The best results will be obtained with a rather low degree of vacuum and with a more than ordinary degree of intensity. Penetration No. 3 or No. 4 Benoist.

The late Dr. Kassabian[2] reported radiographs showing tumors of the trachea and vocal cords.

THE CHEST

Fluoroscopy is of greater value in examination of the chest than almost anywhere else. The relatively slight density of the lungs

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[1] Riforma Medica, Dec. 23, 1905.

[2] New York Med. Journ., Feb. 23, 1907, p. 379.

and the thinness of the chest walls permit sufficient radiance to pass through to give a good image on the screen. Fractures, or disease of the clavicle or ribs, are readily detected; those of the vertebræ, and especially of the sternum, being more difficult. The condition of the lungs is very well studied in this way, a tube with a medium vacuum being used and a primary current of about 8 amperes, the anticathode being 15 or 20 inches from the chest wall, and either in front or behind. In an entirely dark room, and with a large fluorescent screen, the movements of the diaphragm may be studied, also the translucency of the lungs and a diminution of the latter indicates consolidation of the lung or thickening of the pleura; cavities in the lung also show, and in many cases thickening of the walls of the bronchi and deposits in the lymphatic vessels and glands. Pleuritic effusion or empyema may be determined in this way. The smaller enclosed fluoroscope has the advantage of being available when it is inconvenient to darken the room completely. A prolonged study of the fluoroscopic image is dangerous to operator and patient. The heart can be distinctly seen and each pulsation watched. It is often desirable to estimate the size of the heart with an approach to accuracy and for this purpose the orthodiagraph is of service. One model is illustrated in Fig. 664. It consists of tube-stand and fluorescent screen-holder combined in such a way that they move simulta-

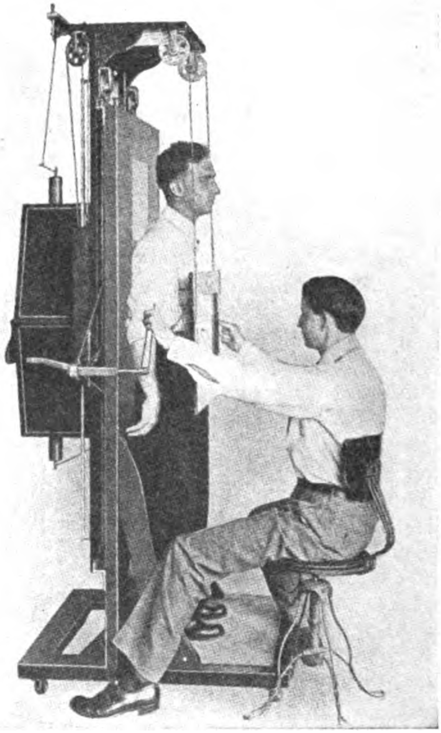

Fig. 663.—Fluoroscopy. Tube enclosed in opaque case. Screen moves with it and is covered by lead glass. Safety to the operator would be attained by his standing aside and viewing the fluoroscopic image in a mirror (Scheidel-Western Co.).

neously like the prongs of a pitchfork. At the center of the screen is a lead pencil which, when the screen is moved, makes a tracing on a sheet of paper which is held in a fixed position. The patient's chest is between the *x*-ray tube and the paper over which the screen and pencil move. When the image of the upper part of the heart appears to be at the center of the screen it means that the tube and the upper border of the heart and the lead pencil are all at the same level. A mark made there is actually at the level of the upper border of the heart. In the same way the actual level of the lower border may be marked on the paper and by carrying the screen and its pencil along the visible border of the image an outline is drawn which is of the natural size. This is true in spite of the fact that the heart is at a considerable distance from the screen, and that consequently its visible image at any stage is enlarged in proportion to its distance from the plate. The tracing consists, then, of a number of points representing the true position of portions which they represent on the border of the heart. A convincing demonstration of this is to place a key rather close to the paper and another of the same size much further away and quite close to the *x*-ray tube. The fluoroscopic image of the first is of about the true size, while that of the second is greatly magnified, yet, on passing the pencil around the borders

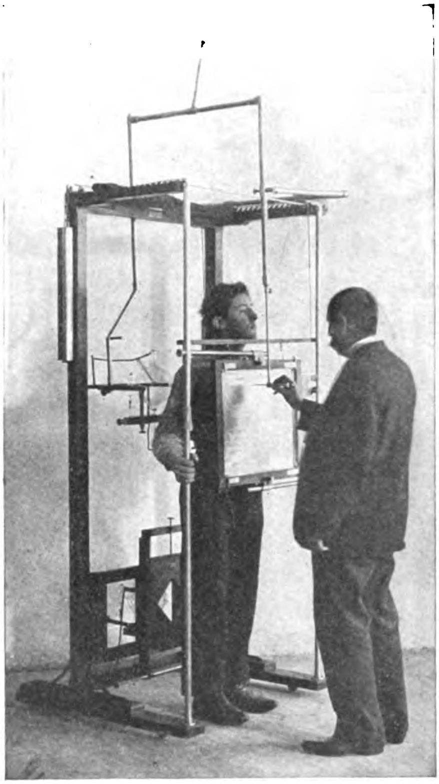

Fig. 664.—Orthodiagraph. This involves a dangerous exposure of the operator and patient.

of the two images, both tracings are found to be of the same size, and that is the true size of the keys. The orthodiagraph does not usually provide the means for making a radiograph showing the true size of the heart; the result obtained is only a pencil tracing of the orthodiagraphic image. The apparatus may be arranged so that the tube is under a table on which the patient lies with the paper and screen above him. The present author made early experiments looking toward the discovery of a method of orthodiagraphic radiography, notably by the use of a cellular screen, the principle being that the *x*-ray is allowed to escape only through a group of nine parallel tin cells, each ¼ inch in diameter and 5 inches long. The tube is enveloped in a localizing shield in the orifice of which the group of cells is fixed. The whole is suspended by a cord long enough to permit of motion in every direction far enough to

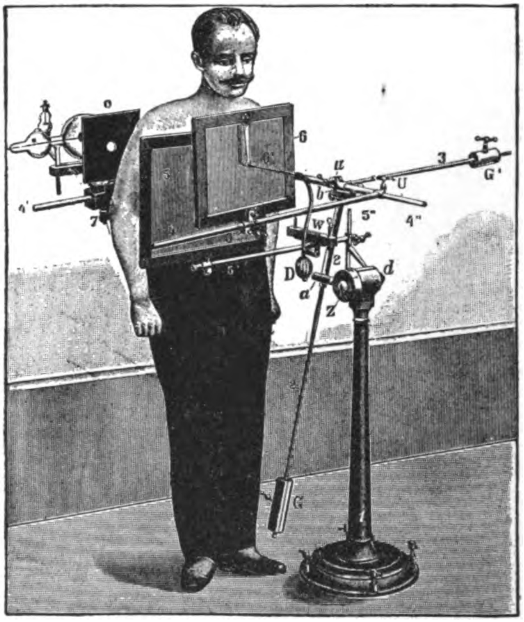

Fig. 665.—Orthodiagraph with two screens.

cover the entire organ to be depicted, and permitting the group of cells to remain vertical all the time. The plate lies flat upon a table, the portion to be radiographed on top of that, and the tube is suspended just high enough not to let the end of the cellular screen touch the flesh. As not more than a square inch of the plate receives the rays at one time, the duration of the exposure would have to be as many times longer than normal as there are square inches in the picture desired. This does not mean that the patient is exposed to the *x*-ray an abnormal length of time. Each square inch of the required area of the patient receives a normal exposure. Naturally, one would make the picture much more than the dimensions required to show the actual size of the organ or foreign body under examination. The image of any very small object, like a needle, is more blurred by this method than by ordinary radiography.

A variation in the orthodiagraph has been suggested by Groedel.[1] It consists in placing the paper and the crayon behind the *x*-ray tube. This enables one to place the fluorescent screen directly in contact with the patient. There is only a small metal pointer, which moves over the surface of the screen and does not interfere at all with an accurate view of the image. The crayon is in a line continuous with the normal ray.

One form of orthodiagraph[2] has two screens (Fig. 665), one for the orthodiagraphic tracing, with a small diaphragm in front of the *x*-ray tube, and another for a general view with the diaphragm removed.

This may be used to make an orthodiagraphic radiograph by first making a tracing of the heart and the general landmarks of the chest without the small diaphragm. Then applying the latter and putting a photographic plate in place of screen No. 5 (Fig. 665) carry the pointer over the same pencil lines again.

Orthodiagraphy is very far from being indispensable. An ordinary radiograph, made with the tube at the proper distance from the plate to correspond with the thickness of the part examined, will give an image from which a correct estimate of the size of the object may be made. The ordinary radiograph or the stereoscopic radiograph has the advantage of giving a first-class picture of the object, and of all that part of the body which the orthodiagraph, either tracing or radiographing, practically cannot do.

Radiography of the chest may be performed with the object of securing good detail of the bony structures or good detail of the lungs. For the bones, the tube should be of rather low vacuum (resistance less than 2 inches and radiometer about No. 4 Benoist), exposure, forty seconds with 18 amperes, this being the strength of the primary current in an induction-coil with a Wehnelt interrupter. A transformer, with a secondary current of 60 kilovolts and 30 ma., producing an intensity of about $\frac{1}{3}$ Tousey, requires an exposure of five to eight seconds. An intensity of radiation of at least $\frac{1}{30}$ Tousey is required and will necessitate an exposure of five minutes. These different exposures give equivalent results upon a photographic plate, the patient lying on his back upon the plate, and the tube at a distance of 19 inches from anticathode to plate. Shorter exposures under the same conditions will produce pictures which are very good, but not quite so substantial appearing. For the detail in the lungs I prefer the same method as above, and the result may be best obtained if the picture is taken in so short a time that the patient can hold his breath and the chest be motionless during the entire exposure. To obtain still more rapid pictures of the chest an intensifying screen may be used. The exposure may be reduced to a snapshot. Instantaneous radiography of the chest has been attempted in the sense in which the term instantaneous is used in regard to snapshot photographs with a kodak camera; and with an extremely powerful apparatus (p. 722) one-quarter or one-half second excellent exposures are practicable without an intensifying screen and of $\frac{1}{10}$ that time with a screen.

In radiographing the chest the best pictures are obtained with the lowest degree of vacuum which will show clearly through the chest with

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[1] Münch. med. Woch., 1906.

[2] Röntgen Congress, May, 1905, exhibited by Polyphos Co.

the fluoroscope. Such a vacuum will take a little longer to produce a picture, but the result will be both better contrast and better detail than with a higher vacuum.

Aneurysm of the aorta shows very well in a radiograph and so do deposits in the mediastinal glands and foreign bodies in the esophagus and lungs. By allowing the patient to swallow an emulsion of bismuth or iron, which is very opaque to the *x*-ray, we may demonstrate the presence of a diverticulum or a stricture of the esophagus.

The dorsal vertebræ are best studied in a radiograph made with the tube 5 inches to one side of the median line, so that the shadow of the sternum will fall to one side of that of the spine—plate behind, tube in front of patient.

The Diaphragm.—Diaphragmatic paralysis is readily detected by means of the *x*-ray.[1]

Commencing pulmonary tuberculosis is indicated by diminution of translucency at one apex and lowering of the corresponding half of the diaphragm.[2]

The convexity of the diaphragm in its average position on the right side is 16½ centimeters below the horizontal episternal line, and 18½ centimeters below this line on the left side. The amplitude of movement is the same on both sides, and is about 18 millimeters. The relation between the amplitude of excursion and the functional angle of the ribs varies in different normal individuals, according to the respiratory type. The conditions in the amplitude of excursion on either side may have a pathologic significance.[3] Reduction in the functional angle is suggestive of tuberculosis.

The Costal Angle.—Guilleminot[4] and Bouchard and Guilleminot[5] have made an especial study of this angle in its relation to pulmonary diseases. It is described as the angle between a line drawn from the center of the sternum to the upper border of a rib during inspiration, and another similar line drawn during expiration. These two lines are traced by means of the orthodiascope or in two radiographs. This angle varies directly as the amplitude of the oscillation of the diaphragm. It is very much diminished in pleurisy and in tuberculosis.

The Cardiac Area.—The cardiac area is reduced in persons with a tendency to consumption, and also in persons with pulmonary tuberculosis. It is larger than normal in cases which have recovered from tuberculosis.[6]

Topography of the Thoracic Organs in Radiographs. (The Tube at the Level of the Sixth Dorsal Vertebra.)—1. *Anteroposterior Radiograph with the Plate Behind* (Fig. 666).—The *spine* shows quite clearly in the upper part of thorax and neck, the spaces between the bodies of the vertebræ being very strongly marked. It shows as a darker shadow with parallel borders in the part of the picture where it is covered by the heart, but sometimes the separate bodies of the vertebræ may not show distinctly. The spinous processes of some of the vertebræ in this region may show as small rounded spots.

The *trachea* shows as a clearly defined band of translucency, extending

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[1] Claude, Congress of Tuberculosis, Paris, 1898.
[2] Beclere, Congress of Tuberculosis, Paris, 1898.
[3] Guilleminot, C. R. de l'Acad. des Sciences, 141, 281, July 24, 1905.
[4] Le Radium, Sept. 15, 1905.
[5] C. R. Acad. des Sciences, cxxviii, 1429, June 12, 1899.
[6] Guilleminot, C. R. de l'Acad. des Sciences, 140, 812, March 25, 1905.

down in front of the vertebræ to the level of its bifurcation (sixth dorsal vertebra).

The *bronchi* and their branches, inside and outside of the lung, cannot ordinarily be seen in the radiograph.

The *clavicles* show distinctly, and so does their articulation with the manubrium sterni.

The *sternum* is not usually distinctly visible in the dorsal radiograph, only its manubrium can ordinarily be traced.

The *ribs* show very well, and even those overshadowed by the heart can be traced in the plate.

The *lungs* show a certain mottling, which is apparently the shadow of blood-vessels and not of air-passages. It is important to distinguish this from the abnormal appearance due to tubercular deposits.

The *cardiovascular mass* (Fig. 666, from Rieder[1]) shows a shadow which is bounded as follows: Beginning close to the border of the spine the edge of the shadow of the superior vena cava passes down almost parallel with the border of the spine and merges into the shadow of the right auricle. The convexity of the latter extends the width of the spinal shadow to the right, and then curves in again to merge into the right ventricle at the intersection of the diaphragm and the spinal column. Then the cardiac outline is lost in the shadow of the spine. At the left of the spine the shadow of the ventricles is at first continuous with that of the diaphragm covering the liver and stomach, but later diverges from it. The apex of the heart is free from any other shadow, and is about twice the width of the shadow of the spinal column from the left border of the latter. It is not quite at the lowest level of the cardiac shadow. From this point the border of the shadow passes upward and inward, showing a slight concavity where the left ventricle merges into the left auricle, and having a convexity over the pulmonary artery, which is at a considerably higher level than the convexity of the right auricle. There is quite a distinct angle between the border of the pulmonary artery, passing upward and inward, and that of the aorta, which passes upward with a slight convexity outward.

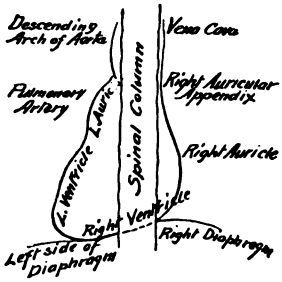

Fig. 666.—Diagram of radiographic appearance of the thoracic organs with the tube in front and the plate behind (Rieder).

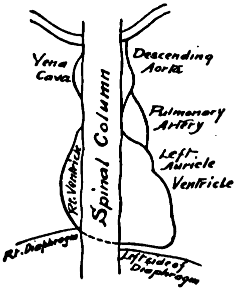

Fig. 667.—Cardiovascular topography with the x-ray tube behind and the plate in front (Rieder).

2. *Cardiovascular Topography in an Anteroposterior Radiograph with*

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[1] Fortsch. a. d. Geb. der Roentgenst., 1902, vol. vi, p. 118.

the Plate in Front.—The spine looks larger and less distinct, the clavicle smaller and more distinct. The heart area is a little smaller and more distinct. In this picture (Fig. 667, from Rieder[1]) the border of the vena cava begins at the junction of the shadows of the right clavicle and the right border of the spine, and forms a slight convexity as it passes down, but before it reaches the cardiac area it is covered by the spinal shadow. The border of the right ventricle becomes visible at a lower level and forms a convexity which terminates at the junction of the diaphragm and the spine. It should not extend more than half the width of the spinal shadow beyond the right border of the latter. From the left border of the spine the shadow of the left ventricle and the apex of the heart extend outward. It may appear in direct contact with the diaphragm, but very often a strip of lung is seen to intervene in this ventral position, especially if the *x*-ray tube is at quite a high level behind the back. The left ventricle and the left auricle and the pulmonary artery form three distinct convexities, extending upward and inward to a point near the spinal shadow, where the border of the descending aorta is seen close to the spinal shadow, and extending down from the clavicle to the heart area; it is only slightly convex.

(Weinberg's Atlas der Radiographie der Brust Organe, E. M. Engel, Vienna, 1901, gives an excellent guide to the topography in anteroposterior radiographs of the chest.)

A convexity in the second left intercostal space extending outward from the median shadow in an anteroposterior radiograph is not usually due to an aneurysm. It is commonly due to the aorta being placed a little farther to the left than usual.

A diffuse swelling of the aorta is sometimes seen in old persons, especially in a radiograph taken with the tube behind and to the left. It indicates atheroma, not usually aneurysm.

Radiography in Other Than the Sagittal Plane.—The first investigations of the thoracic organs by means of *x*-ray examination, made in a number of different directions, were by v. Criegu[2] and by Holzknecht.[3]

Rieder[4] has done more than anyone else to make the oblique and lateral methods of examination practicable.

The tube is usually placed at the level of the sixth dorsal vertebra, and generally at a distance of not more than 50 or 60 centimeters from the plate.

3. *Topography of the Heart and Great Vessels in Oblique Radiographs of the Thorax.*—These pictures are made with the tube at the level of the sixth dorsal vertebra, and either in front or behind at an angle of 45 degrees from the median line, the plate being diametrically opposite.

With the Tube Behind and to Either Side.—The two oblique pictures with the tube behind show the spine somewhat curved, its concave border smooth and formed by the bodies of the vertebræ; its convex border uneven and formed by their transverse and spinous processes and confused by the angles of the ribs. The shadow of the spine is large and somewhat vague.

The clavicles show at a different angle upon the two sides.

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[1] Fortsch. a. d. Geb. der Roentgenst., vol. vi, p. 118.

[2] Verhand. d. Kongress. f. in. Medizin, Karlsbad, 1899.

[3] Wien. Klin. Woch., 1900, No. 10, and Die Roentgenologioché Diagnostik der Erkrankungen der Brustemgeweide Hamburg, Lucas Gräfe and Sillen, 1901.

[4] Fortsch. a. d. Geb. der Roentgenst., vol. vi, 1902, p. 114.

With the Tube in Front and to Either Side.—The spinal column shows more distinctly; it is curved and the concavity is smooth, formed by the bodies of the vertebræ, while the convexity presents a notched border, due to the different processes of the vertebræ and to the angles of the ribs.

The two scapulæ present quite a different appearance. The one on the same side as the plate presents its customary appearance, while the other one is seen in profile, and seems like a cylindric bone not more than an inch in diameter, extending downward from the shoulder-joint.

(*a*) *The Cardiovascular Shadow When the Tube is Behind and to the Left* (Fig. 668).—Its right border may be traced from below, where it is formed by the right auricle. It is separated from the spinal shadow by a translucent area, and as it passes up parallel with the border of the spine it is formed by the ascending aorta. The arch of the aorta casts quite a broad shadow, which ends abruptly in the translucency of the lung substance at the level of the clavicles. The left border passes down and to the left, and is formed by the arch of the aorta, the descending aorta, the pulmonary artery, and the left ventricle. It merges into the shadow of the diaphragm at the apex of the heart. The entire cardiovascular shadow looks like that of a tenpin used in bowling-alleys.

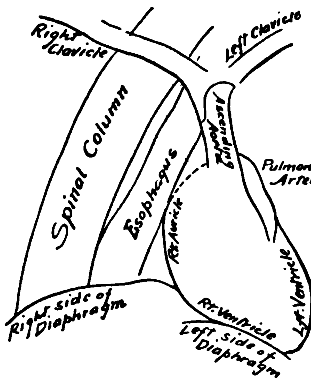

Fig. 668.—Cardiovascular topography: Plate in front and to the right; x-ray tube behind and to the left; angle of 45 degrees with the median plane.

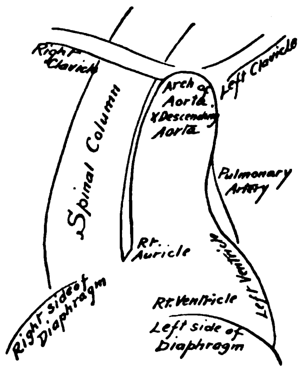

Fig. 669.—Plate in front and to the right; x-ray tube behind and to the left; angle a little less than 45 degrees with the median plane.

The *esophagus* passes down through this transparent space between the heart and the spine, and may sometimes be made out in the radiograph as a dark strip. Its course is rendered more visible by the introduction of a metallic sound. This oblique radiographic position is favorable for the detection of foreign bodies, strictures, or diverticula of the esophagus. Diseases of the esophagus are considered on p. 914.

(*b*) *Topography of the Cardiovascular Mass in a Radiograph with the Tube Behind and to the Right.*—There is the same clear space between the heart and the spine, but somewhat narrower, and this is almost in the median line, as indicated by the episternal notch. The shadow of the esophagus may be visible.

(*c*) *Topography in Radiographs of the Chest with the Tube in Front* *and to Either Side.*—The cardiovascular mass casts a shadow which is enlarged and indistinct. It is covered by numerous shadows of the pulmonary blood-vessels. The spinal column shows particularly well in such a picture.

Oblique radiographs are especially valuable in the diagnosis of aneurysm, lesions of the esophagus, and tumors of the mediastinum.

Lateral Radiography of the Chest.—This is only practicable in thin and slender patients, and only with the tube on the right side. The pictures are vague, weak, and do not even give a good image of the ribs. The reason for this is that there is a great thickness of tissue to be traversed, and consequently great absorption of the *x*-ray and great dispersion or development of secondary rays.

Normal Radiographic Appearance of the Heart and Great Vessels.—Arcarisi[1] has studied this subject in healthy persons of various ages and of both sexes. He finds that the shadow of the whole cardiovascular mass presents in all cases an indented and vertical right border which does not pulsate. This outline is produced partly by the vena cava. The left margin pulsates, passes from the pulsating apex obliquely upward and inward almost to the border of the sternum, and then from about the level of the second intercostal space curves outward to form a pulsating semicircle. The latter is formed by the shadows of two vessels which overlap; the left portion of the arch of the aorta and the pulmonary artery. These two pulsating portions of the cardiovascular shadow are often seen separately in old persons and others in whom the entire mass is somewhat elongated. The shadow increases in width as well as in length as the person becomes older. It is quite short in children (Fig. 661, p. 912), where the abdomen is so much more developed than the chest.

Alterations of the Cardiovascular Area in Disease.—An increase of intra-abdominal pressure shortens the shadow of the cardiovascular bundle. Pleural effusions or adhesions variously displace or deform it. Cardioptosis (Rummo's disease) causes elongation and displacement downward, with slight increase in width at the base and with two separate pulsating areas at the left side instead of a continuous one. The appearance in this disease is very different, according to whether the patient is lying down or standing up.

Enlargement or reduction in the size of the heart shows in the radiograph.

Pericardial effusion shows as an increase in the cardiac area, with probable diminution in the visible pulsation. Such a radiographic diagnosis was reported by Janeway,[2] in which 54 ounces of fluid were removed by tapping.

A Röntgen ray diagnosis of compression of the superior vena cava by an aortic dilatation was made by Dopter[3] in the case of a man with cyanosis, edema of the skin of the chest, pallor, cold extremities, tachycardia, but no cardiac murmurs.

The Aorta.—This normally shows, especially with the tube in front, a shadowy fluoroscopic image, starting from the heart and rounded at the top, where it reaches the level of the top of the sternum. It forms a broad even band, which is very dark and which pulsates with the heart.

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[1] Reforma Medica, Aug. 19, 1903, abstracted New York Medical Journal.

[2] New York Medical Journal, May 11, 1907.

[3] Revue de Medicine, Sept., 1900.

Holzknecht[1] has made numerous observations upon dead and living, normal and diseased persons, which confirm the above statements.

Aneurysm of the Aorta.—This condition is evidenced by an unnatural extension of the normal shadow of the upper part of the cardiovascular mass. The shadow pulsates and varies in position, according to the part of the aorta which is affected. Baetjer,[2] from a study of 104 cases, gives the following classification: (1) Aneurysm of the ascending aorta gives a shadow which extends more to the right than to the left of the sternum. It lies above the heart, and is nearer the anterior than the posterior thoracic wall. (2) Aneurysm of the arch of the aorta produces a shadow which extends a little further to the left of the sternum and to various levels toward the neck. It lies nearer the anterior than the posterior wall of the thorax. (3) Aneurysm of the descending thoracic aorta casts a shadow to the left of the sternum and is in relation with the posterior wall of the thorax.

The cases which have been referred to the author have often presented the *x*-ray appearance of an abnormal opaque mass in the upper median part of the chest, suggestive either of a mediastinal tumor, tubercular or malignant, or of an aneurysm. In one case the patient was a large young man of apparently splendid physique. The rational symptoms and physical signs were suggestive either of tuberculosis or aneurysm, and the radiograph was regarded as probably, but not certainly, indicating aneurysm. The patient died a few weeks later from a single sudden hemorrhage, which was regarded as positively arising from the rupture of an aneurysm.

Many radiographs of tubercular cases show an area of opacity in the upper part of the chest continuous with the cardiac shadow and extending to one side of the spinal shadow. One patient had all the symptoms of pulmonary tuberculosis except hemoptysis and died a few months later of exhaustion. The condition of the rest of the lung will aid one in deciding whether such a shadow is cast by consolidated pulmonary tissue or by an aneurysm.

Aneurysm of the Innominate Artery.—Kassabian[3] reported a radiograph showing an aneurysm of the innominate artery. The diagnosis was confirmed by a post-mortem examination.

The various positions of thoracic aneurysm, as revealed by the *x*-ray, have been classified by Baetjer[4] as follows:

(1) Aneurysm of the ascending portion of the aorta usually casts a shadow more to the right than to the left of the sternum above the heart, and by localization would be found to be nearer the anterior than the posterior wall of the thorax.

(2) Aneurysm of the transverse arch casts a shadow slightly to the left of the sternum, and this shadow extends well up into the neck, and by localization would be found nearer the anterior wall.

(3) Aneurysm of the descending arch of the aorta casts a shadow to the left of the median line, and by localization is found rather nearer the posterior than the anterior wall.

In a case reported by Walsham[5] the symptoms were apparently

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[1] Wien. Klin. Woch., March 8, 1900.

[2] Bull. Johns Hopkins Hosp., Jan., 1906.

[3] New York Med. Jour., Feb. 23, 1907, p. 379.

[4] Johns Hopkins Hospital Bulletin, 1906.

[5] Lancet, Nov. 3, 1900.

those of mediastinal tumor, but the x-ray enabled one to make the correct diagnosis of aneurysm. Radiographs taken at different times showed marked variations in size which could not occur in a solid growth.

Guilleminot[1] has even attempted to radiograph the aorta at different phases of the cardiac cycle.

Transposition of the Heart.—This condition, suspected from the physical signs, is verified by the radiograph. We may also be enabled to say whether it is a congenital malformation, as in a case of the author's, or due to displacement by pleurisy and the like.

Estimation of the Size of the Heart.—(1) This may be done by means of the orthodiagraph (Moritz), and a tracing made by the pencil while the operator carries the central ray around the outline of the heart.

(2) Another method is by the author's simple home-made apparatus, p. 918.

(3) The orthodiagraph may be used to accomplish the same result of orthophotography (Lepper-Immelmann) by having a small diaphragm in front of the x-ray tube and carried with it. This diaphragm may be in the shape of a slit, adjustable so as to be perpendicular to the border of the heart at each part to which it is carried.[2]

The author's simple method and Lepper-Immelmann's method both accomplish the same result of making a photographic record of the cardiac area on a sensitized plate instead of a pencil tracing made by the operator, as in ordinary orthodiagraphy. The plate, in any case, should be in contact with the patient, and the latter should not move or turn during the exposure.

The Lepper-Immelmann method has the advantage over the author's that it enables the operator to guide the beam of x-ray by direct observation of a fluorescent screen placed behind the photographic plate, instead of guessing at the area that ought to be covered by the moving ray of light.

The way in which the photographic record of the boundary of the heart is produced is explained in the paragraph on the author's orthoradiograph.

(4) Simple radiography or fluoroscopy may be employed to measure the size of the heart. Fluoroscopy, with the tube at a distance of 2 meters (80 inches) from the screen which is placed directly in contact with the patient, gives an approximation to the actual size which is close enough for every practical purpose. The room should be darkened for a few minutes before the examination is made. The screen should be fastened in position and have a sheet of lead glass over it to protect the operator. Tracing-paper covers the glass, and the operator traces the outline of the heart with a heavy graphite crayon (a packer's marking pencil).

A radiograph would have to be made at a shorter distance and due allowance made for magnification.

Teleradiography, with the tube 80 inches (2 meters) away, is rendered practicable by the very powerful modern transformers.

Effect of Cardiac Movements upon Röntgen Ray Measurements.—These are so small, relatively, as not to interfere with this method of examination.

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[1] C. R. Acad. des Sciences, cxxiv, 177, July 17, 1899.

[2] Gillet, Fort. a. d. Gebiete d. Roentgen, vol. x, No. 4, p. 249, Nov. 29, 1906.

Position of the Patient.—Where the greatest possible exactness is required, as in making repeated examinations of the same patient, the recumbent position is best.

This position is restful to the patient, who is compelled to hold still during the process of mensuration. Other advantages noted by Moritz[1] are that the respiratory movements are more ample and the heart acts more regularly; the diaphragm occupies a median position, not being displaced by the traction of the weight of the liver or by the intestines; the abdominal wall is relaxed.

The size of the heart shadow is always smaller in the upright position, it also descends in front of the diaphragm, and is dragged down by traction of the diaphragm upon the pericardium.

Sometimes the position is not important. Simple fluoroscopy, with the tube at a distance of 80 inches, is only practicable with the patient in an erect position.

The tube may be in front of or behind the patient, with a slight preference for the former position when the patient is erect as it gives a better view of the vertebræ and ribs and hence more exactly locates the heart.

The tube should be under the patient's back when the horizontal position is chosen for fluoroscopy.

Rieder's Method for Orthoradiography of the Heart.[2]—The patient lies face up on Moritz's horizontal orthodiagraphic couch, the tube being underneath. A tracing of the outline of the heart and diaphragm is made upon a sheet of paper held in a horizontal position over the patient's chest; then, without changing the position of the patient or of the paper, a photographic film (Lumiere "Sigma" or a film made by the Berlin Aniline Co.) between two intensifying screens is slipped between the patient and the tracing paper. The iris diaphragm over the *x*-ray tube is cut down to an aperture of only 6 or 7 millimeters, and the current is again turned on and the orthodiagraphic pencil is again slowly drawn over the tracing of the outline of the heart and diaphragm. The thin bundle of *x*-rays, always kept perpendicular to the plane of the photographic film, is carried around the outline of the heart and diaphragm. It makes a continuous series of pictures of small portions of the cardiac border which unite to produce a single permanent image upon the plate. The exposure required for the final tracings is thirty seconds, with the anticathode at a distance of 24 inches from the film, or twenty seconds at a distance of 16 inches. The patient should hold his breath during the time that the final tracing is being made.

A longer time, one or two minutes, will be required if a photographic plate is used instead of a film with intensifying screens. Only a small part of the patient is exposed at a time, so that there is no danger from overexposure, but it is impossible for the patient to hold his breath for such a length of time. The image is consequently less clearly defined than in the other case.

A thin strip of heavy sheet lead is placed along the middle of the patient's sternum to indicate the median line in the image on the photographic film.

The Pulmonary Lymphatic Glands.—The condition of the pulmonary lymphatic glands may be studied by the *x*-ray, the best image

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[1] Deutsch. Arch. f. Klin. Med., 82, 1, 1905.

[2] Arch. f. Phys. Med. and Med. Tech., Oct., 1906.

being obtained with the fluoroscope and with a very small diaphragm. Scarcely more than a square inch of the wall of the chest nearest the tube is exposed to the *x*-ray, and the area visible in the fluoroscope is not more than 2 inches in diameter. Such a diaphragm may consist of a couple of large sheets of lead, mounted in a frame which can be slid up and down very much like a window. The arrangement for making the aperture larger or smaller may be as simple or as complicated as the manufacturer desires. The author's contact diaphragm (in contact with the *x*-ray tube) gives a larger field with equal definition.

An arrangement which affords excellent protection for operator and patient besides enabling one to shift the tube readily to any height and change the size of the diaphragm at will is described by Albers Schönberg.[1] The tube is enclosed in a lead box of ample size fastened on a pedestal, which is counterbalanced so that it can move freely from one height to another, and will remain in any position in which it is placed. The diaphragm is a rotating lead disk with a number of holes of different sizes.

The arrangement employed by the author and shown in Fig. 503 is fully described on p. 761. It has the advantage of being adapted to general radiography and radiotherapy, since the impervious tube box can be placed above or below the operating table and inclined at any angle. It is a modification of Ripperger's and Brickner's stands.

According to the post-mortem studies of Piery and Jacques,[2] a calcareous condition of the glands indicates an old and safely healed tuberculosis. Sclerotic spots make the condition of a healed pulmonary tuberculosis seem only probable, while cheesy degeneration indicates an active process.

A case radiographed by the author showed lungs filled with opaque patches, indicating sclerosis of various groups of lymphatic glands. The case was that of a man about forty years old, with considerable emaciation and loss of strength, but without pulmonary symptoms. A physical examination by one of our best diagnosticians led to the report that the lungs presented the signs of old pleuritic adhesions with probable tuberculosis. Another equally well-known physical examiner was perfectly positive that the patient did not have tuberculosis. The *x*-ray findings caused the author to recommend a partial relaxation from business sufficient to provide for a certain amount of out-of-door exercise. This has been followed by very great improvement.

Calcareous bronchial glands sometimes show more clearly on deep inspiration than during expiration.

Calcified pulmonary glands contrast quite sharply with the surrounding lung tissue.

Abscess of the Lungs.—This is shown by the *x*-ray, no matter in what part it may be located. An abscess presents an area of opacity as compared with the translucency of the aërated tissue of the lung. The outlines are clearly defined, and generally are more or less regularly circular in shape.

The condition from which abscess of the lung might require to be differentiated is in pyopneumothorax. The *x*-ray findings in the latter case are that of a small area of lung at the upper part of the chest with very much greater than the normal density, an area of almost total

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[1] Fortsh. a. d. Geb. d. Roentgen., vol. vii, No. 3, April 7, 1904, 149.

[2] Revue de Med., 1906, No. 6.

opacity at the lower part of the chest, and a larger or smaller area of unnatural translucency between these two. In the case of an abscess of the lung, on the other hand, the opaque area is usually surrounded by an area of approximately normal translucency.

Differential Diagnosis of Pleural Thickening and Effusion and Pulmonary Abscess.—Pleural thickening shows a less uniformly dense shadow than effusion. It is quite possible to diagnose a small loculated effusion or empyema by means of the x-ray, which would require many exploratory punctures to locate.

An abscess-cavity when emptied sometimes becomes still more evident, with its thickened walls and unnatural central translucency.

Empyema, whether loculated or not, presents a dense shadow, which enables one to distinguish it from resolving pneumonia with its less homogeneous shadow.

A case reported by Talley[1] showed what appeared in the fluoroscopic and skiagraphic images to be an empty abscess in the upper part, and a filled cavity in the lower part of the right side of the chest. The autopsy showed that the inference was correct in regard to the empty cavity above, but that the supposed filled abscess-cavity below was in reality a bronchiectasis in which the bronchial tubes were filled with secretion.

An interesting case is reported by Anders and Pfahler,[2] in which the development of a pulmonary abscess was observed radiographically. The first radiograph was made three days after the abscess had attained its maximum size. It was made with the patient lying supine, with the plate underneath, and after inspiration. It showed an incomplete consolidation of the right lower lobe, with an abscess-cavity about 2 inches in diameter extending from the upper border of the fifth rib, posteriorly, to the middle of the second intercostal space in the midscapular line. Four subsequent radiographs showed the gradual disappearance of consolidation, the reduction of the abscess to a cavity ½ inch in diameter, and an elevation of the diaphragm to the level of the eighth rib. The latter was a natural process assisting in obliterating the abscess-cavity.

Rieder reports cases of abscess of the lungs in which the radiograph showed a cavity, in the bottom of which fluid could be seen, which produced waves when the patient was shaken. He thinks it important in the sequelæ following pneumonia to make an x-ray examination, as abscess of the lung seems to be commoner than has previously been supposed.

Intrathoracic Tumors.—Tumors of the lung, usually metastatic, show sharply defined dark areas, surrounded by the transparent pulmonary tissue. Enlarged bronchial glands must be of a quite considerable size in order to produce a shadow. Their shadows are sharply limited, and if they are produced by peribronchial glands will appear arranged in chains.

Mediastinal tumors can be confused with aneurysms only when their borders are sharp and regularly curved. If the outlines are irregular and vague, aneurysms can be excluded.[3]

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[1] Jour. Am. Med. Assoc., Sept. 8, 1906.

[2] New York Med. Jour., Aug. 4, 1906, p. 257.

[3] Burdach and Mann, Fortsch. Geb. d. Roentgen., vol. x, No. 1, July, 1906.

X-RAY DIAGNOSIS OF EARLY PULMONARY TUBERCULOSIS

Fluoroscopy.—Five important phenomena indicate this condition (Walsham and Orton): (1) Diminished range of motion of the diaphragm on the affected side (Francis Williams).

(2) One or both apices fail to light up in the fluoroscopic image on deep inspiration.

(3) The diseased part of the lung casts a dark shadow.

(4) The heart is usually smaller and placed more vertically in the chest.

(5) Any alteration in the shape of the chest and position of the ribs may be better determined by the x-ray than by other methods.

The *first* sign is, perhaps, due to pleuritic adhesions and is very frequently absent in recent cases. It is important if present, but its absence does not exclude tuberculosis.

The *second* sign is of very great diagnostic value. The affected apex may even become darker during deep inspiration.

The *third* sign is of great value.

The *fourth* sign is the subject of some doubt. Bouchard and Balthazar have found the heart smaller than normal in the first and second stages of tuberculosis and believe that this acts as a predisposing cause. They find that the heart generally becomes enlarged in the third stage of pulmonary tuberculosis by a compensatory hypertrophy, due to the increased resistance in the pulmonary circulation. It is interesting to note in this connection that the heart has been reported to be larger than normal in cases of healed tuberculosis.

The *fifth* sign is of value.

Other Fluoroscopic Signs of Early Tuberculosis.—The condition of the bronchial glands may be studied with the fluoroscope and is especially easy to determine with a very small diaphragm.

The Costal Angle and the Functional Angle.—The measurement of the costal angle is important. Measurement of the costal angle is made by noting the obliquity of one of the ribs at the moment of inspiration or expiration. The functional angle is the difference between these two degrees of obliquity.

Radiography.—A radiograph will show the differences in density of parts of the lung, the difference in the size of the heart, and the changes in the position of the ribs alluded to above.

The usual position is lying down, with the plate under the back and the tube over the chest and in the median line. No diaphragm need ordinarily be used, but it may be required for an extremely accurate radiograph, especially of the apices of the lungs.

Radiographic Findings in Tuberculosis of the Apex of the Lungs.—These have been made the subject of study by a great many observers. Adam, in connection with Albers Schönberg,[1] has made use of the compression diaphragm, examining 70 cases, and believes that this method gives better results than any other. (It requires a certain definite position to obtain the image of the apex of the lung free from the bone shadows.)

It seems to be impossible to get the shadow of the apex of the lung entirely free from the shadows of the bones, but a position in which the plate is behind the neck with the tube in front in the median line gives an image which is crossed by the shadows of the first and second

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[1] Fortsch. d. Geb. Roentgen., vol. x, No. 3, October, 1906.

ribs, but the opacity of the apex of the lung shows through the shadows of these ribs as well as through the intercostal space. The method is to have the patient lie on his back upon a wedge-shaped cushion, whose upper surface makes an angle of about 24 degrees with the horizontal line. The upper extremity of the cushion terminates at the level of the shoulders and the head can be bent backward over it. The plate is placed behind the nape of the neck. A compression cylinder, with a 13-cm. diaphragm, is so placed that the rays pass in an oblique direction from in front upward and backward, covering an area extending from the lower part of the larynx to the junction of the manubrium and the body of the sternum. Sometimes the second, third, and part of the fourth intercostal space can be shown in such a picture. A moderately low degree of vacuum is used, and the Lumiere Sigma plates are recommended, with an exposure of ten to fifteen seconds. The patient should hold his breath during the exposure, which is preferably at the moment of deepest inspiration.

The normal lung shows shadow lines upon the plate which are nearly at right angles with the shadows of the ribs, and which are due to the bronchi and their accompanying blood-vessels. If these shadows are not clearly visible in a good picture it is an indication of trouble. Such plates are apt to be unsuccessful with patients who have short fat necks, and also in cases of kyphosis or scoliosis.

One of their characteristic plates showed a cloudy shadowing of the whole second right intercostal space, with dark and bright spaces. The third and fourth intercostal spaces in the same case were flecked with cloudy areas. The bony shadows of the ribs and clavicle were altogether deeper than on the left side and somewhat spotted. On the left side there were circumscribed spots in the second intercostal space.

More or less diffuse areas of cloudiness were found in all cases where the physical examination gave evidence of distinct dullness. Circumscribed spottings were found in cases where the physical examination revealed only catarrhal symptoms, but not in all of these.

Another case showed decided spotting in the second and third intercostal spaces, though with very little interference with the general transmission of the *x*-ray through both apices. This, combined with the physical signs, indicated a catarrhal infiltration on the left side, while on the right side catarrhal râles were heard without any indication on the plate.

Still a third characteristic plate showed two very dense and sharply defined shadows, about twice the size of a pinhead. The contrast between the right and left second intercostal spaces was sharply marked. In the third, fourth, and part of the fifth intercostal space there was a difference in the general brightness of the two sides, but here, where so much thickness of lung tissue has to be penetrated, the judgment as to whether the appearance is pathologic or not is much more difficult than at the apex. The general effect upon the fluoroscopic screen was that the left apex was smaller and more dense.

The plate showed a spotted cloudiness in the second left intercostal space, an evidence of some thickening, which, however, was not extensive enough to make a difference in the percussion note. The two small sharp shadows were supposed to indicate calcification in a caseous focus.

The fourth characteristic plate showed diffuse spotting of the second, third, and fourth intercostal spaces, which was also visible upon the shadows of the clavicle and of the third rib. The upper border of the clavicle did not seem sharp. This last feature, of course, was only of value when the patient had held his breath during the exposure. With the fluoroscope the apex appeared cloudy, while thickening was visible in the lower part of the right lung. This plate showed that the infiltration extended much lower than the percussion note would have indicated. It also shows that increase in pulmonary density is visible even through the ribs.

The following conclusions are drawn from the 70 cases which Albers Schönberg and Adam examined in this way:

An acute catarrh does not give any Röntgenographic evidence, but thickening of the lung tissue can be discovered by the *x*-ray before it is extensive enough to produce a change in the percussion note. Consequently, an *x*-ray examination is desirable for cases in which the disease has progressed for some time in the form of chronic infiltrative processes of both apices without catarrhal symptoms.[1]

Shurly[2] states that the *x*-ray demonstrates the fact that pulmonary tuberculosis may progress to the formation of small cavities before ordinary skill in percussion and auscultation will detect it, and also that an *x*-ray examination at the time of the earliest hemoptysis or fever will often show much more extensive lesions than are indicated by the physical signs. The author's own cases corroborate this statement.

Bonney's book on pulmonary tuberculosis contains excellent radiographs illustrating different stages of tuberculosis.

Pfahler's excellent radiographs of cases of pulmonary tuberculosis[3] illustrate the different conditions revealed by the *x*-ray in this disease.

A patient of the author's had been perfectly well up to three months previously, when she had a severe cold. This was followed by another, and since that time she had rapidly lost flesh and strength and had frequent hemoptyses. A radiograph taken with the author's radiating cellular diaphragm showed the entire right upper lobe clearly outlined and denser than any other part of either lung.

Radiographic and Fluoroscopic Findings in Advanced Pulmonary Tuberculosis.—Consolidation is evidenced by a dark shadow.

Cavities are seen as very transparent, circumscribed areas, surrounded by a zone of opacity representing their thickened walls.

Pleuritic adhesions are evidenced by diminished movement of the diaphragm. Pleuritic thickening is shown by a slight shadow, usually without distinct borders, and pleuritic effusion or empyema is shown by a deep, clearly defined shadow.

Pneumothorax shows a large area of unnatural transparency and a small area of unnaturally opaque lung.

Pyopneumothorax is similar in radiographic appearance, but with the addition of a clearly defined area of dense shadow at the most dependent part, and this may show wave-motion when the patient is shaken.

Calcified foci in the lung tissue or in the bronchial glands show as very opaque spots.

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[1] Fortschritte d. Geb. d. Roentgen., vol. x, No. 3, p. 183.
[2] Jour. Am. Med. Assoc., June 16, 1906.
[3] Arch. Physiol. Therapy, Sept., 1905.

The normal outline of the pulmonary vessels may be obscured.

There may be unnatural chains of opacity through the lung indicating deposits in the bronchial glands or in the walls of the bronchi.

All these changes are much more readily appreciable when the plate is examined by transmitted light in a negative examining box than they are in a print made from the plate.

Radiographic Appearances in Healed Pulmonary Tuberculosis.—Von Jaksch[1] has radiographed 5 such cases. One showed a pathologic shadow in the upper part of the right lung and the left apex was not perfect. There was also a shadow on the right side, close to the spinal column, extending down to the diaphragm.

In another case the radiograph showed that more or less of the left lung took no active part in respiration.

Another case showed extensive calcification in the upper lobe of the right lung.

Another case showed evidence of the consolidation of both apices.

Another case showed calcification in the upper lobe of the left lung very clearly.

All these cases had all the regular symptoms of pulmonary tuberculosis, including the presence of tubercle bacilli, and had all recovered from the disease without the use of tuberculin, aided only by suitable diet, etc. At the time of the *x*-ray examinations they seemed perfectly well and the sputum contained no tubercle bacilli.

RADIOGRAPHY OF THE THORAX IN PNEUMONIA

This will enable us to recognize areas of consolidation even in the central portions of the lung, which are difficult to determine by ordinary means of physical diagnosis. It is valuable, both at an early stage if the diagnosis of pneumonia is in doubt, and also at a later stage to determine whether complete resolution has taken place. The therapeutic value of the *x*-ray in the treatment of delayed resolution after pneumonia appears to be very well established.

Radiographs and fluoroscopic examinations show that consolidation begins at the middle of the affected lobe and extends to its periphery. Consolidation shows as increased density, and is recognizable by means of the *x*-ray before it can be diagnosed by the physical signs or by the sputum.

This examination shows the presence of *central pneumonia*, consolidation which never reaches the surface, and which is difficult or impossible to diagnose without the *x*-ray.

Rieder[2] reports in full the histories of 20 cases of pneumonia, followed throughout their course by a series of radiographs. He uses a medium-soft tube and a diaphragm large enough to take in both lungs. This is about the size of the largest orifice of the Friedlander shield. The thickness of the body to be traversed makes it desirable to cut down the inevitable development of secondary rays to the lowest possible quantity. A diaphragm aids in this by eliminating many of the secondary rays starting from the walls of the tube.

Rieder makes a drawing with a grease crayon on a sheet of glass covering the surface of the fluorescent screen and subsequently transfers this to paper.

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[1] Fortsch. Geb. d. Roentgen., vol. x, No. 3, October, 1906.

[2] Münch. Med. Woch., Nos. 26–30, 1906.

An increase in the size of an area of consolidation can be discovered by the x-ray earlier than by any other method. Increase in an anteroposterior direction does not show in an ordinary anteroposterior radiograph and a lateral radiograph is usually impracticable. Rieder recommends stereoradiography in this case. The different stages of consolidation and resolution cannot be closely followed by the x-ray. While there is usually considerable reduction in the area of opacity after the crisis, there is often a faint shadow to be seen long after all the physical signs have disappeared.

Dry pleurisy as a sequela to pneumonia is evidenced by restricted movement of the diaphragm, and pleurisy with effusion by a dark shadow.

Bronchopneumonia may be easy or difficult to recognize, according to the size of the areas of consolidation.

BRONCHIECTASIS

This condition may sometimes be diagnosed on account of light areas in the radiograph of the lung. The best time to make the exposure is directly after a profuse expectoration. An interesting case in which this condition of bronchial dilatation was recognized by the x-ray is reported by Pfeiffer.[1] The x-ray revealed also the presence of a drainage-tube lost in the pleural cavity after an operation for empyema.

Bronchiectasis may be mistaken for abscess of the lung, as the radiographic appearances are similar.

FOREIGN BODIES IN THE LUNG

Bullets are very easily located in any part of the chest. This may be done by means of two radiographs, one anteroposterior and the other lateral, or the localization may be made by the McKenzie-Davidson method. Among the interesting cases of other foreign bodies located in the lung is one of a knife blade broken off in the lung three months before the x-ray examination was made. Meanwhile, symptoms similar to those of advanced consumption had set in. The knife blade was removed without much difficulty after resecting 1 inch of an overlapping rib. The case was reported by Baldwin.[2]

Another interesting case is reported by Russell.[3] The patient was a boy, twelve years old, who had swallowed a large black-headed pin five weeks previously. A week or two later there was cough with blood-stained sputum. Fluoroscopic examination showed the pin to be lying in the left lung with its point upward. The foreign body was removed through an incision made into the lung. The case is exceptional, because foreign bodies almost invariably enter the right bronchus instead of the left, as in this case.

Fragments of a peanut shell, inhaled, did not show in one of the author's cases.

THE LUNG REFLEX

This is a symptom which has been described by Abrams.[4] In effect it is a dilatation of the lung in consequence of a cutaneous stimulus. It is said not to involve both lungs, or even an entire lung, and spreads

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[1] Beitrage zur. Klin. Chir., vol. l. No. 1, 1906.

[2] Annals of Surgery, March, 1903.

[3] Lancet, Sept. 9, 1905.

[4] New York Med. Journal, Jan. 13, 1900.

from a source of cutaneous irritation involving primarily certain spots, then, if the irritation is severe enough, more remote parts may be involved. It can be excited in lungs showing diminished resonance, the resonance being always increased by rubbing the skin over the lung percussed. It is used as a test of the resiliency of the pulmonary structure. In the *x*-ray examination normal lungs present a uniformly light area, which appears brighter during inspiration than expiration. The increased translucency due to reflex lung dilatation may be observed with the fluoroscope. It lasts for about two and a half minutes. It is used in the differential diagnosis of lung dulness due to consolidation or to atelectasis. If the dulness is due to atelectasis, as in some cases of bronchial pneumonia, cutaneous stimulation by vigorous friction or the use of cold water produces this increased translucency to the *x*-ray by expansion of the air-vesicles. It does not take place in consolidation.

RADIOSCOPY OF THE ESOPHAGUS

This subject has been discussed on p. 911.

RADIOGRAPHY OF THE SPINE

This will aid in the diagnosis of Pott's disease if the radiograph shows the presence of an abscess and erosion of the body of a vertebra. This examination in the lumbar region presents the same difficulties and requires the same technic as for renal calculi. It is less difficult in the upper dorsal and cervical region. For all these parts of the spine the patient lies supine on the plate, while the tube is over the median line in front at the appropriate level. The use of a compression cylinder for the lumbar vertebræ reduces the size of the picture, but increases its clearness. The lower dorsal region, where the spine lies behind the heart and liver, presents difficulties which may be partly overcome by taking an oblique picture with the tube in front and to the right and the plate behind and to the left. The patient must hold his breath during the exposure, which, therefore, should not last much more than thirty seconds.

Radiography of the Entire Length of the Spinal Column.—This may be done, as in one of the author's cases, upon a glass plate 24 inches in length, or upon a celluloid film, for instance, the Lumiere Sigma film, the same size, or upon Röntgen paper, made by the Neue Photografische Gesellschaft, Berlin-Stieglitz, whose agents in America are the Rotograph Company of New York. This paper is about as rapid as an *x*-ray plate and is much more economic.

The patient should lie flat upon his back upon the table, with the tube over the lower end of the sternum and the anticathode 25 inches from the plate. An intensity of $\frac{1}{15}$ Tousey, produced by an induction-coil with a primary current of 18 amperes, a penetration of No. 8 Benoist, and an exposure of fifty seconds, would be suitable for a child weighing about 90 pounds. A larger person or a less powerful radiance would require a longer exposure. A transformer, with a secondary current of 50 ma. and an intensity of $\frac{1}{3}$ Tousey, requires an exposure of two to five seconds. The portion of the spine covered by the liver can be seen only very faintly, but it is possible to trace the general line of curvature.

The author's contact diaphragm makes it possible to secure good definition in a picture of this size. It cuts out the secondary rays arising from the greater part of the *x*-ray tube while permitting the direct rays to radiate through a wide angle, and this causes increased definition and contrast in the radiograph.

The difficulty in spinal radiography does not consist chiefly of insufficient *x*-ray reaching the plate, but in a lack of contrast and detail, due to secondary rays originating in the thick mass of tissue traversed. This is remedied by the use of a diaphragm cutting off the secondary rays arising from the *x*-ray tube, which increases the contrast and detail in spinal radiographs to a wonderful extent.

Radiography in Scoliosis.—An interesting observation has been made by Boehm[1] in regard to the etiology of this lateral curvature of the spine. Anatomic study shows that it is frequently associated with numeric asymmetries of the spine, so that a vertebra has a certain character on one side, while presenting on the other side the characteristics of a vertebra either higher or lower in the spinal column. An example of this is afforded in the case of a cervical rib and also in case of atypic sacral wings. These numeric anomalies occur at the cervicodorsal, dorsolumbar, or lumbosacral junctions. Boehm found them present in 17 out of 20 cases examined with the *x*-ray. Especial care is necessary to detect these conditions. He explains the fact that scoliosis does not appear until puberty on the ground that all the vertebræ are of practically the same type until that time.

Typhoid Spine.—McRae[2] reports a case in which the *x*-ray revealed definite changes in the vertebræ. Dunlop[3] thinks that many cases of supposed typhoid spine are in reality cases of relaxation at the sacroiliac articulation. The *x*-ray may enable one to differentiate between these two conditions.

The changes reported by McRae in a patient suffering from typhoid spine were actual bony lesions of the spinal column itself. The *x*-ray plate showed the presence of newly formed bone. He says that not all cases of typhoid spine present such organic lesions, and some of them are possibly functional.[4]

Spondylitis Deformans.—This is a disease sometimes of tubercular origin, and sometimes accompanying syringomyelia or other conditions. The intervertebral cartilages become ossified, and this condition may be revealed by a radiograph. The remaining lesions perceptible by the *x*-ray are the rigidity of the spine, in a position either of a straight "poker-back" or of kyphosis, and possibly some of the bony deposits around all the articular parts of the vertebræ and ribs. Le Breton[5] reports cases in which the *x*-ray was useful in making a differential diagnosis. In a case of my own the ankylosis was in the cervical spine and it was difficult to secure a favorable position of the *x*-ray tube and plate.

Bullet Lodged in the Spinal Canal.—An interesting case, in which a bullet passed through the spleen, stomach, vertebræ, and spinal cord, where it was located by the *x*-ray and removed, is reported by Pegram.[6] The patient recovered.

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[1] Am. Orthoped. Assoc. Annual Meeting, Aug. 2, 1906; Jour. Am. Med. Assoc., Sept. 6, 1906, p. 801.

[2] Annual Meeting, Assoc. of Amer. Physicians, 1906.

[3] N. Y. Med. Jour., Dec. 8, 1906.

[4] Ibid., May 26, 1906, p. 1106.

[5] Ibid., March 16, 1907.

[6] Med. Progress, Jan., 1907.

THE ABDOMEN AND PELVIS

A convenient method of fluoroscopy is to have the patient stand with his back toward the tube and with the fluoroscope in front. A medium degree of vacuum (resistance, 2½ inches, radiometer, No. 5 Benoist) and a primary current of about 10 amperes' intensity No. 10 Tousey are employed, the anticathode being about 15 inches from the surface of the body. The size and mobility of the liver and spleen can be noted at a glance, and so can the presence of any large dense mass, like an appendicular abscess or hydronephrosis. Generally speaking, however, pathologic conditions in this part of the body require a radiograph and the fluoroscope may be dispensed with, or if used it had better be for a very short time.

Radiography of Biliary Calculi.—Radiography is of value in the diagnosis of gall-stones, but this is one of the most difficult conditions in which it is used. The plate, with a sheet of *x*-ray metal under it and a sheet of blotting-paper over it, should be laid upon a table, and the patient may lie face down upon it. A plate measuring about 10 × 12 inches should be used, and this is placed so that its center is at the free border of the ribs and 3 inches to the right of the median line. The tube is placed vertically above the center of the plate, the distance from the anticathode to the skin being 13 inches or more. The vacuum should be medium, resistance 3 inches, and radiometer No. 7 Benoist, the exposure two minutes with 10 or 12 amperes, intensity $\frac{1}{16}$ Tousey, or one minute with 15 amperes, intensity $\frac{1}{14}$ Tousey. Much shorter exposures are practicable with apparatus employing a primary current of 30 to 40 amperes, and a transformer makes exposures of one to seven seconds practicable. The difficulty is that most biliary calculi present very little resistance to the passage of the *x*-ray and show no contrast with the surrounding tissues. The stomach and intestines should be empty. By this method the anterior extremities of the ribs are shown more clearly than any other bony structures, but by the dorsal method the vertebræ and posterior extremities of the ribs ought also to show very well.

Gall-stones present a resistance to the passage of the *x*-ray that is very slightly different from that of the abdominal tissues. A gall-stone, ¾ inch in diameter, held in the closed hand, can be traced in a radiograph, but with difficulty, not at all like a bullet or piece of glass. Nevertheless, a mass of gall-stones in the gall-bladder presents a shadow, though not so dense as a solid tumor or any other solid mass would present, if surrounded to some extent by the translucent gaseous contents of the intestines. This shadow thins out at the edges where the *x*-ray passes through only a small thickness of calculus material and its outlines may be very vague indeed. The central portion of the shadow, due to the thickest portion of the mass, may be moderately dense, and still the light and shadows of this part of the abdomen may disguise it or normal shadows may simulate this. A plate like this requires long development, and trifling inequalities in the sensitiveness of the film may produce an apparent shadow where one does not really exist.

Imperfections in the plate present the appearance of shadows or more often of increased transparency. Misinterpretation of the spots may be avoided by using two plates, one under the other. A spot which shows on both plates is presumably due to conditions in the body of the patient, and a spot which shows on only one of the plates is presumably due to an imperfection in that particular plate.

A rather large shadow, with vague outlines in the gall-bladder region, may be stated to be compatible with the existence of a mass of gall-stones. It is always extremely difficult to say positively that gall-stones exist. Some cases, like one diagnosed by the author, p. 963, present clinical symptoms suggestive of gall-stones, but if the radiographic shadow is as dense at the periphery as at the center, and if the borders are sharply defined, it may be stated that it is not due to a mass of gall-stones. In the case referred to the mass was due to hydronephrosis.

The most that the radiographer ought to say is that the radiograph is or is not the kind of one that would be produced by gall-stones.

In making the radiograph the plate may be placed upon the table and the patient lie upon it, either supine, with the plate over the middle of the abdomen at a considerable distance, at least 22 inches from the plate, or prone, with the tube over the back, at a distance of at least 22 inches from the plate.

The *supine position* gives a better image of the spine, but the gall-bladder is as far as possible from the plate, and its image is, therefore, magnified and indistinct. Any kind of compression is helpful in this regard. A thin rubber bladder made for the air-container in a foot-ball may be about half filled with air and placed over the gall-bladder region. It may be pressed down by bandages passed over the abdomen and pulled tight to each side of the table, or the rubber air-bag may be compressed by the author's board compressor. The board compressor alone is not very useful for these cases, because the portion to be compressed is close to the ribs.

Albers Schönberg's compression-cylinder may be used for the same purpose. It gives a clear image of the spine, and as clear an image of the gall-bladder as either of the other means of compression, but it gives only a small picture, not over 8 inches in diameter.

In the *prone position*, with the tube over the back, the element of compression may be obtained by laying an 8×10-inch plate upon a book or piece of wood the same size and putting it under the abdomen, or the rubber air-bag may be placed on top of the plate and under the abdomen, but this has the disadvantage of keeping the part to be radiographed away from the plate. This offsets the advantage gained by reducing the thickness of tissue to be traversed by the *x*-ray. The board compressor (Fig. 677) is useful to immobilize the patient, and produces compression in a corpulent person to effect a reduction of an inch or more in the thickness of tissue. The compression cylinder accomplishes the same result as the board compressor, with the added clearness resulting from cutting off the secondary rays, but with the disadvantage that the picture is a small one.

Beck[1] suggests that the patient lie face down upon the plate, with a pillow under the symphysis pubis and another under the sternum to allow of protrusion of the gall-bladder region. He has the patient lie somewhat on his right side and has the *x*-ray tube still further to the right, so that the rays make an angle of 45 degrees with the plate.

A radiograph of a case of suspected biliary calculi may be made simply of the gall-bladder region, and then a compression-cylinder or

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[1] N. Y. Med. Journal, Jan. 20, 1900.

some similar apparatus, like a protective shield, may be used to limit the rays of this particular part and cut off the secondary rays. The radiograph will be a small one with excellent detail, which will answer the question as to the condition of the gall-bladder, but it does not take in the other kidney, the ureters, and bladder, which are often under suspicion in these cases.

A radiograph upon a 14×17-inch plate takes in all of these regions, and it is possible to get excellent detail upon it.

Radiographs which seemed to show the presence of gall-stones subquently removed by operation have been published by Beck.

Two Cases Examined for Suspected Biliary Calculi.—The radiographic findings in these 2 cases are instructive. Each patient, brought to me by Dr. Beaman Douglas, had a palpable swelling in the region of the gall-bladder and had pain and other symptoms suggestive of gall-stones.

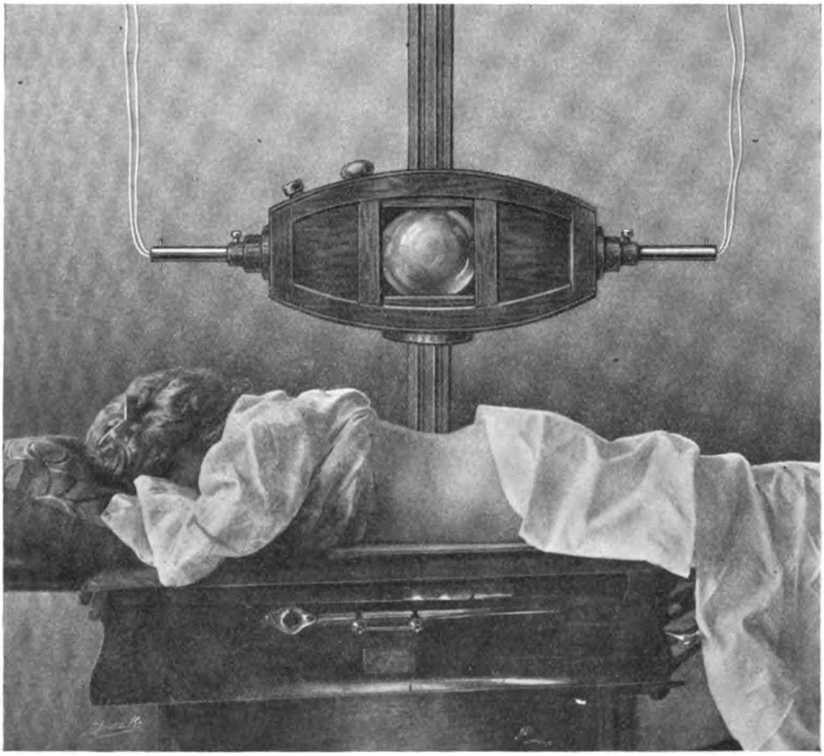

Fig. 670.—Radiography for biliary calculi. A diaphragm should be used, preferably the author's contact diaphragm with a 2-inch orifice.

The Author's Report on the Two Radiographs Made of the First Case.—"The first picture showed a vague area of opacity, extending down from the liver region on the right side of the spine, which corresponded in position and appearance with the shadow that a collection of gall-stones would cast. These have a density or degree of opacity to the

x-ray which differs so little from that of the flesh that they do not show as sharply defined areas in a radiograph.

"The first picture showed certain perfectly defined masses in the region of the lumbopelvic articulation. Their absence in the second picture, taken with the stomach and intestines entirely empty, shows that they were fecal in nature.

"The second picture showed the same vaguely defined shadow below the liver region, obscuring the image of the ribs on that side, while those on the other side are quite plainly visible.

"The conclusions to be drawn from these two pictures are, in the first place, that there is no renal, ureteral, or vesical calculus present, and, in the second place, the picture exactly corresponds to that which would be found in a patient with a collection of gall-stones and without any great amount of fluid in the gall-bladder. It cannot be stated positively that gall-stones are present, but it seems probable."

A collection of gall-stones were found when the operation was performed.

The Author's Report on the Two Radiographs Made of the Second Patient.—To avoid repetition the reader is referred to p. 963, on which this report is to be found. The radiograph showed that the case was not one of gall-stones, but probably of encysted fluid. An operation showed the correctness of this interpretation; the fluid being due to hydronephrosis.

Hepatic Abscess.—A case in which this disease simulated pulmonary tuberculosis and in which the x-ray revealed the true condition is reported by Quadrone.[1]

THE STOMACH AND INTESTINES

In all radiographs through the abdomen and pelvis the bowels should be thoroughly emptied and no solid food or milk, which forms opaque coagula, should be taken for twelve hours previously. In many radiographs the course of the colon and different other parts of the intestines may be recognized, the air-filled portions being more transparent than the rest.

The *best position* is with the patient standing with the x-ray tube behind at the level of the umbilicus and with the plate in front.

The size, shape, and position of the stomach may be determined by making a radiograph with an emulsion of bismuth, oxychlorid or subcarbonate, or of barium sulphate (specially purified for radiology), or of black oxid of iron, which is less satisfactory, or of zirconium oxid ("Contrastin," introduced by Kaestler).[2] It requires two to four times the dose of bismuth in the stomach. This can be introduced into the stomach and subsequently withdrawn through a tube, and is quite harmless even if swallowed in the ordinary way. The radiograph may be made with the patient lying either face down upon the plate or face up, or with the patient standing and the plate in front. The tube should be of medium vacuum, resistance 2½ inches, radiometer No. 5 or 6 Benoist, anticathode 10 to 15 inches from the surface of the body. The thicker the patient, the further the tube should be from the surface of the body. Exposure should always be made as short as possible by the use of the best intensifying screen. This is to prevent danger to the patient

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[1] Gazz. d Ospedal e. d. Cliniche, Nov. 27, 1904.

[2] Münch. med. Woch., 1909, No. 50.

from the repeated exposures required and also produces clearer pictures of the parts undergoing peristaltic movement. The best results are only obtainable with an apparatus which will give a full exposure in a small fraction of a second. The different transformers and the unfluctuating converter will do this in one-quarter second or, with anything like the maximum power, in a much shorter time. With the patient lying supine upon the plate the radiograph should show all the vertebræ, their bodies, and transverse processes. Foreign bodies in the alimentary canal, or in the bladder, or in the tissues of the abdomen are located by the same kind of a radiograph. The progress of a mass of food and metallic emulsion through the alimentary canal can be studied in successive radiographs, but owing to the cumulative effect of the *x*-ray a limited number would be desirable in the human subject.

Pancoast has seen poisonous effects from leaving large quantities of bismuth subnitrate in the stomach, and advises removing it with a stomach-tube as soon as possible if over an ounce has been swallowed.

Bade[1] suggested, in 1899, filling the stomach with gas in order to secure a radiograph showing its size, shape, and position. He swallowed some Seidlitz powder and had a radiograph made of his stomach, which was better than any pictures obtainable up to that time by administering opaque substances.

Cole and Einhorn[2] revived this practice, but it has proved less useful than the other method.

Pfaff and Nelson[3] have made 60 fluoroscopic studies of the effect of laxatives upon peristalsis. In cats, after the ingestion of food mixed with bismuth, peristalsis could be readily watched.

Dangers from the Ingestion of Bismuth Subnitrate and Desirable Substances for It.—From 1 to 2 or even 4 ounces of bismuth subnitrate may be required, and if there is a deficiency of hydrochloric acid a quantity of nitrites may be produced. Two or more deaths and several cases of dangerous depression have occurred which are attributed to this reaction.

Bismuth subcarbonate is thought to be perfectly safe in doses of 1 or 2 or even 5 ounces, but bismuth oxychlorid is still better in the same doses, because it does not excite any reaction in the stomach. Bismuth oxychlorid[4] does not relax the pylorus sooner than natural food and does not cause constipation. It may be given well stirred up in a bowl of bread and milk.

The Bismuth Meal.—A convenient formula is a portion of mashed potato with 2 or more ounces of bismuth oxychlorid and a glass of water. Another excellent one is von Gourevitsch's potato-flour decoction with bismuth[5], employed by the present author. An ounce of potato flour, ½ ounce of almond syrup, 6 ounces of milk, and 1½ ounces of bismuth oxychlorid are thoroughly mixed and poured into 9 ounces of boiling water. The mixture is stirred until it has boiled for two or three minutes.

Zoolak and bismuth, suggested by Pfahler, has been extensively employed by the author and is to be very highly recommended.

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[1] Deutsche Med. Woch., No. 38, 1899.
[2] N. Y. Med. Jour., May 18, 1907.
[3] Jour. Am. Med. Assoc., Feb. 1, 1906.
[4] Hertz, Arch. Roentgen Ray, June, 1908, p. 3.
[5] Fortsch., xix, Oct. 24, No. 3, 214.

Adopting a suggestion of Lewin,[1] the author has employed black iron oxid without any inconvenience to his patients, but the results are not so good as with bismuth. The metallic powder is mixed with mashed potato.

Gastric Findings with the Rontgen Ray.—An increase in the vertical length of the stomach is seen in cases of gastroptosis and enteroptosis, and anything which causes a loss of the fatty layer in the abdomen; thus it may be seen after the Weir Mitchell treatment; and the stomach may show increased motility on change of posture or pressure.

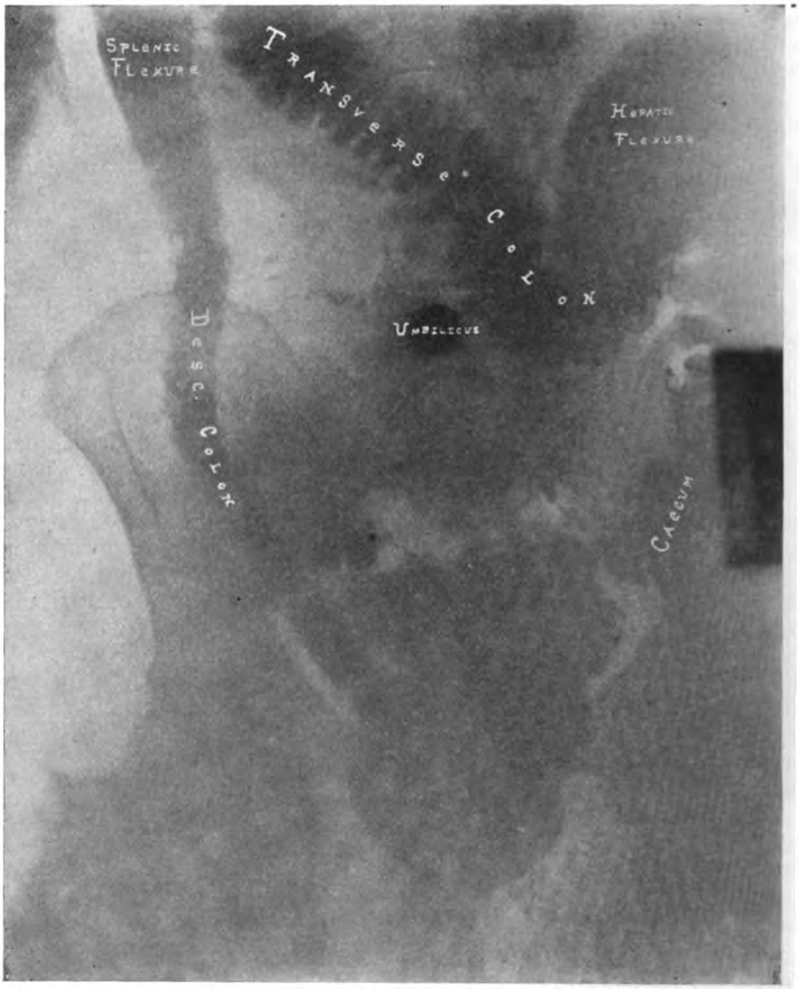

Fig. 671.—Marked angulation of transverse colon with narrowness of descending colon.

Dilatation of the stomach occurs chiefly in pyloric obstruction by cancer or by adhesion following perforating ulcers of the pylorus or duodenum (Fig. 671). The outline of the stomach with its bismuth meal

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[1] Münch. med. Woch., March 30, 1909, p. 641.

is clear and sharp in these cases even when the patient is recumbent. The cases in which dilatation is atonic and not obstructive show in the recumbent position an indistinct outline. The shadow is that of a pool of dense liquid deep and opaque in the middle, but shallow and increasingly transparent near the edges.

Changes in Form.—One of these is the hour-glass contraction (Fig. 672), due sometimes to cicatricial contraction after ulcer, or to perigastritis with adhesions, or to carcinoma. It is sometimes spasmodic in cases of gastric ulcer. Circumscribed defects in the outline of the bismuth shadow of the stomach indicate pressure from without or caused by the growth of a tumor in the wall of the stomach.

Changes in Motility.—Peristalsis and changes of position, produced by normal pressure or by change of posture, may be studied with the fluoroscope or by means of a series of radiographs either cinematographic or at longer intervals.

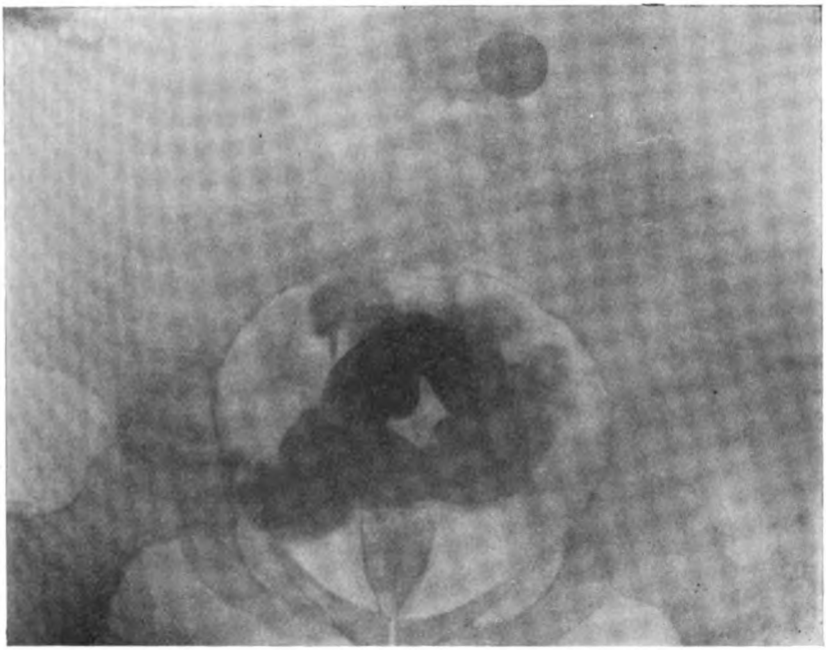

Fig. 672.—Radiograph of rectum and sigmoid flexure.

The length of *time that food is retained in the stomach* is of the greatest importance, and can be better and more safely determined by a series of radiographs than by fluoroscopy. In a state of health the bismuth has usually left the stomach in two or three hours. As short a time as one or two hours is sometimes found in hyperacidity and also sometimes in pyloric insufficiency; in the latter the stomach empties itself more quickly if the patient lies upon his right side.

A radiograph is usually made six hours after a bismuth meal, and if it shows retention this may indicate atony or pyloric obstruction. The latter may be due to cancer or perforated ulcers with adhesions. In a case referred to the author by Dr. Robert C. Kemp fully half of the meal was found in the stomach six and eight hours later. The stomach was large and extended vertically downward on the left side. At the operation there were found perforated ulcers of the pylorus and duodenum, with adhesions to the pancreas, colon, and every neighboring tissue. Twelve hours, and even twenty-four hours, retention occur in the worst cases of pyloric or duodenal stenosis.

Schlesinger's[1] intermediate layer shows as a horizontal band between the shadow of the bismuth meal and that of the magen-blase. It is supposed to vary in width and quickness of formation with the amount of acidity. It would be prominent in ulcer and absent in cancer. It is prominent in catarrhal gastritis.

Gastric Ulcer (x-Ray Diagnosis).—A case of hypersecretion examined for Dr. Kemp had had sick headaches from the time he was seven years old, and there had been regurgitation of bile and gastric juice possibly containing pancreatic juice. This condition had been only temporarily relieved by an operation upon the gall-bladder. The patient would go to bed after having the stomach emptied by a stomach-tube, and on aspiration the following morning, before taking any food or drink, the stomach would be found to contain a pint or more of gastric juice containing neither visible or occult blood. The fluoroscope, after a bismuth meal, showed that the stomach was in a vertical position, large and flaccid and with sluggish peristalsis. A radiograph made three and one-half hours later showed an irregular spot of bismuth adherent to the wall of the stomach near the cardiac orifice. The rest of the bismuth was in the last part of the small intestine and in the ascending colon. A diagnosis of ulcer of the stomach was followed by appropriate treatment and cure.

Difference in Appearance Between Ulcer and Cancer of the Stomach.—The niche symptom (Nischensymptom in German) is characteristic of perforating ulcer and may occur in any ulcer. It means that a radiograph taken shortly after a bismuth meal shows a certain spot of great density where the bismuth extends into a cavity, and there is often a large magen-blase and a marked intermediate layer. If the ulcer is at either curvature, the shadow may project beyond the general outline.

Cancer, on the other hand, cuts out a portion of the bismuth shadow of the stomach and is often failing in an intermediate layer.

M. Haudek[2] notes the following differential points between gastric ulcer and cancer: Ulcer is apt to cause pyloric spasm and retard emptying of the stomach; the outline of the stomach shadow is smooth; cancer at an early stage causes gaping of the pylorus, and later may produce stenosis with greatly prolonged retention of the bismuth meal in the stomach; cancer produces a jagged outline of the shadow.

Possibility of Resection of Gastric Carcinoma Indicated by the Radiograph.—The more favorable cases are those in which the fish-hook outline of the lesser curvature and pylorus are retained.

Radiography in Intestinal Obstruction.—Just as in the case of stricture of the esophagus a bolus of metallic emulsion will show in a radiograph of the abdomen, and its position a certain number of hours or days after its ingestion will indicate the site of an intestinal

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[1] Schlesinger, Eine Aciditatsbestimmung des Mageninhaltes mittels des Röntgenverfahrens. Vereinsbericht, Med. Klinik, 1911, S. 950.

[2] Wein. klin. Woch., January 11, 1912, xxv, 2, p. 67.

obstruction. In a case reported by Einhorn[1] 30 gr. of bismuth subnitrate in a pint of milk were swallowed. The radiograph, taken twenty-four hours later, showed a dense mass filling a part of the intestines, then a contracted portion where there was no bismuth, and a portion beyond that was filled with it. The location was thought to be in the large intestine, and to test this matter another radiograph was made five days later, after the original amount of bismuth had all been passed. Before making the radiograph 30 gr. of bismuth in 500 cc. of water had been injected into the rectum. The same radiographic appearances were found and, as it was extremely unlikely that the injection had passed beyond the ileocecal valve, it was regarded as quite positive that the stricture was in the large intestine.

Radiography of Intestinal Adhesions.—A case (Fig. 671) examined by the author for Dr. Robert C. Kemp suffered greatly from constipation, attributed to adhesions following one or two operations upon the pelvic organs. The symptoms pointed to the sigmoid flexure or the rectum as the seat of obstruction; but the picture, after a bismuth enema, showed that while the entire large intestine was in normal position and permeable to the injection an almost empty region remained in the transverse colon. The injection distended the parts on both sides. It seemed as if this condition could only be accounted for by pressure either from a tumor, which could be excluded, or from a band of adhesions. The latter was found at operation.

The *recumbent position,* the patient lying upon his back with the plate underneath, is often used by the author, because displacement of the stomach and intestine which are not corrected by this position are usually rendered permanent by adhesions.

The Duodenum.—Radiographs, as a rule, do not show this part of the intestine at all, or only as a shadowy outline, making a curve around the pylorus with its concavity toward the left. Einhorn's method of blocking the duodenum by inflating a rubber ball, passed into the duodenum by an esophageal bougie, gives an excellent picture of the duodenum when successfully accomplished, and, of course, the rare cases of stenosis of the duodenum from cancer or ulcer also cause it to show in the radiograph. The bulbus duoden or cap may show as a dense shadow, separated from that of the stomach by the clear space of the pylorus without indicating any lesion.

In some of the author's cases a small dense shadow has been seen at one part of the duodenum six hours after the ingestion of a bismuth meal, and this, combined with the symptomatology, has been taken as indicating duodenal ulcer; and this diagnosis has been confirmed in the cases which have been operated on. Six hours after a meal the bismuth is commonly to be seen far down in the pelvis or low down on the right side, either in the last part of the small intestine or in the cecum and ascending colon. This fact makes any separate shadow at that time close to the median line, and near the second or third lumbar vertebræ, suspicious of duodenal ulcer.

In the majority of cases no particular information in regard to the jejunum and ileum is obtained in the *x*-ray diagnosis; but, of course, any very great obstruction from any cause would be shown by the arrest of the bismuth meal at that point. Lane's kink may be revealed in this way.

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[1] N. Y. Med. Journ., May 18, 1907.

The **appendix** is sometimes to be seen in radiographs made after a bismuth meal, or after an injection of bismuth or barium. The fact that it is visible does not indicate any lesion.

The **colon** is usually best studied from a radiograph made after a rectal injection of about 2 pints of a liquid holding in suspension barium sulphate or bismuth oxychlorid.

Formula for Injection.

Barium sulphate	3 ounces.
Bolus alba	½ pound.
Water	2 pints.

Such an injection fills every part of the large intestine from the anus to the ileocecal valve, and some of the author's radiographs show that even this is sometimes passed.

Normally, the colon forms a sort of letter H, with the splenic flexure reaching far up under the ribs; the hepatic flexure, extending not quite so high, but still well above the level of the umbilicus; the transverse colon at about the level of the umbilicus (somewhat higher when recumbent than when standing); and the sigmoid flexure, extending from well down in the left side of the pelvis, up out of the pelvis, and then down again into the rectum.

Changes in Position of Colon.—In cases of enteroptosis the shadow of the transverse colon may fall far down in the pelvis, but on operation in the recumbent position this may be found to have been somewhat exaggerated in the picture. Cases of old adhesions, like Fig. 672, a patient of Dr. Kemp's who had been operated upon for appendicitis and pericolitic adhesions, sometimes show the hepatic flexure much below its normal level and the whole ascending colon and cecum fallen together, instead of extending up along the right side of the abdomen.

Normal Passage of Food Through the Colon.—There is a to-and-fro peristalsis, which favors the absorption of the nutrition from the colonic contents and a slow general progress toward the rectum, with occasional forward motion of a mass occupying a large part of the length of the colon. Holzknecht first observed this, and found that it takes place only once in about eight hours.

Obstruction of the colon would show by arrest of the bismuth meal and also of the rectal injection. A case of the author's, also a patient of Dr. Kemp, has very marked constipation following operations upon the appendix and ovaries and uterus. A bismuth injection was given, but no meal.

The radiograph in the recumbent position showed the normal outline of the colon, but at the place where the transverse colon crossed the spine there was a clear area 3 inches in length. This was evidently a portion of the colon through which the liquid injection could readily pass, but which was kept flattened out instead of becoming distended. The picture was so good as to make this quite positive, and its appearance suggested pressure upon the colon where it crossed the prominent vertebræ. This sometimes produces a similar aspect and must be guarded against. In this case it was excluded by the fact that the place in question was at the upper part of the abdomen and the line of demarkation was very sharp. Another possibility was pressure from a tumor, but there were no signs of this in the radiograph or upon palpation. The probability, therefore, was that it was due to pressure by a band of adhesions. Upon operation by Dr. Parker Syms there was found a band of adhesions 3 inches broad and encircling two-thirds of the circumference of the gut.

Changes in the Size and Motility of Different Parts of the Colon.—Megacolon, or megacecum, show, by an enormously large shadow, and in cases where the first injection of a couple of pints suggests this condition, a much larger injection will reveal the extent of the dilatation. In a recent case the cecum and lower part of the ascending colon were very large, while the caliber of the descending colon was very small. No constipation was present as a result of this condition.

Cecum mobile, or unnatural mobility of the cecum, will be shown by its change of position on pressure. It has been thought to have a causative effect in some cases of appendicitis.

Chronic constipation is often shown to be due to malposition or pressure or contraction at some part of the colon, and sometimes the condition revealed by the x-ray is one requiring operation. It may be shown to be due to simple muscular weakness in the wall of the colon evidenced by long retention in the colon, or it may be shown to be due to adhesions of the rectum or sigmoid producing mechanical obstruction. If the x-ray shows the bismuth meal long retained in the rectum this would indicate lessened sensibility and reflex action there, or spasmodic contraction of the sphincter ani.

The rectum and sigmoid flexure are best seen after an injection which (Fig. 671) does not extend beyond these parts.

The Skiagraphic Enema.—For a rectal injection a decoction of potato flour, 1 ounce to 2 pints of water, is prepared by mixing the potato flour at first with a small amount of cold water and then pouring it into boiling water. Three or 4 ounces of barium sulphate are thoroughly mixed with this liquid (von Gourevitsch). The decoction must be perfectly liquid or it will not flow properly through the tube. This potato mixture gives excellent pictures, and the author prefers it to the following formula, which has only the advantage of requiring no cooking—barium sulphate, 3 ounces; bolus alba (purified powdered kaolin), ½ pound, and water up to 2 pints. Many of the author's radiographs have been made with this mixture and never with any bad effect, but it is conceivable that some of it might be retained and become dry and hard.

Foreign Bodies in the Stomach and Intestines.—These are readily located if metallic, of as large size as a coin, and if the person is not too large. A needle might escape detection.

The x-ray has been used to locate stolen property swallowed by criminals. This is said to have been done at the diamond mines and also in the mint in Japan, and a stolen ring has been located in this way in the prison at Davenport, Iowa.

Radiographic Studies of the Passage of Different Food-stuffs from the Stomach and Through the Small Intestine.—Observations have been made by W. B. Cannon[1] upon a cat, to which 25 cc. of fats, of carbohydrates, or of albumin was given, mixed with bismuth subnitrate. *Fats* were seen to remain in the stomach for a long time, gradually passing into the small intestine as the previous portions of fat were absorbed or passed into the large intestine. There was no accumulation of fat in the small intestine. *Albuminoids* were seen not

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[1] Am. Jour. of Physiology, 12, 388, 1904.

to leave the stomach during the first half hour, except white of egg, which almost immediately passes into the small intestine. The maximum amount of albuminoids is found in the small intestine at the end of two hours. *Carbohydrates* pass directly into the duodenum. A *mixture* of *fats*, *albuminoids*, and *carbohydrates* has an intermediate time of retention in the stomach. The presence of the fats slows the progress of the other two. *Doubling* the amount when carbohydrates are given alone increases the rapidity of passage, but doubling the amount of an albuminoid meal retards it. The moment at which the different foodstuffs administered singly appear in the large intestine is about four hours for carbohydrates, five hours for fats, and six hours for albuminoids.

Radiographic Characteristics of the Stomach in the Infant.—Leven and Barret[1] find that the infant stomach lies in a horizontal position, with a portion of its greater curvature lowermost. It seems always in a condition similar to that known as dilatation, not adapting itself at all times to the volume of its contents as in the adult. After the ingestion of 80 to 175 cc. of milk the infant stomach empties itself in from one and three-quarters to two hours.

Other radioscopic studies of the infant stomach[2] show that it contracts throughout its entire extent, not merely around the pylorus, as in the adult. This contraction is a reflex from the gastric mucosa, and if the latter is hypersensitive, vomiting occurs. Obstinate vomiting of infancy is not a condition of stenosis or spasm at the pylorus, but one of hypersensitiveness, and this may be promptly relieved by the administration of sodium citrate.

Radiography Applied to the Desmoid Test of Stomach Function.—The digestion of connective tissue may be studied by having the patient swallow a capsule made of thin gold-beater's skin and containing 22 gr. of powdered black iron oxid. This is to be taken at the end of an ordinary meal.

A radiograph made seven hours later will show whether the gold-beater's skin has been digested. This, according to some observers, is the average time required; if not, the capsule of iron still shows a distinct dark spot.

G. W. Schwartz[3] found that connective tissue was completely digested in two hours in a case of very marked hyperacidity of the gastric juice.

L. Horwitz[4] has employed Schwartz's method in 44 cases. He gives a little bag of bismuth after a regular test breakfast, and has the patient lie on his left side to retain the capsule in his stomach as long as possible, and the patient should take nothing but tea and water during the entire day. A little piece of thin rubber tissue tied around the bismuth with 00 catgut may be used instead of the bag of gold-beater's skin. The catgut is digested in the same length of time as gold-beater's skin. He says that if radioscopy shows the bismuth as a small opaque spot in the stomach or intestines more than three hours after swallowing it, this indicates a lack of acid in the gastric secretion. When the connective tissue of the bag is digested the

[1] Presse Medicale, August 8, 1906.
[2] Quoted by Variot, Societé Med. de Hôp., Paris, July 6, 1906.
[3] Münch. Med. Woch., Jan. 23, 1906, p. 196.
[4] Arch. f. Verdauungskr., Boas, Berlin, 1906.

bismuth escapes and is seen as a larger and vaguer area of cloudiness, and if this takes place in an hour and a half or less, extreme hyperacidity is present. Freeing of the bismuth in two hours indicates moderate hyperacidity; in two and a half hours, normal stomach digestion; in three and a half hours, slight hypo-acidity; in four to four and a half hours, extreme hypo-acidity; and in five hours, anacidity. The last-named condition was always found in cases of cancer examined in this way.

This is a modification of Sahli's desmoid test, based upon the fact that the raw connective tissue of the bag is not digested by the pancreatic or intestinal secretions, but only by the gastric juice, and only when the latter contains pepsin and free hydrochloric acid.

Schwartz's radiologic observations show that no ingesta of any kind are ever retained for more than ten hours in a stomach of approximately normal size and without stenosis.

Hoffman's conclusions from the radiographic examination of 100 patients with diseases of the stomach are that the x-ray is only occasionally of assistance in diagnosis.

If the stomach is dilated by gas and a bougie is introduced, the latter should normally follow a certain definite curve, but in gastroptosis the bougie is seen in the radiograph to pass almost straight down to an unnaturally low level.[1]

An hour-glass stomach was diagnosed by Holzknecht and Brauner.[2] The radiograph was made with the patient lying upon his back upon the plate with the tube over the abdomen. He had swallowed a sort of paste made of rice and milk and powdered bismuth subnitrate. Two dark shadows could be seen separated by a clear area representing the place of constriction.

Fig. 673 by the author shows an hour-glass stomach resulting from old adhesions. The patient was referred by Dr. Kemp.

An example of the value of the x-ray in the diagnosis of intestinal diseases may be mentioned—a case described by Wiesner.[3] An operation for appendicitis was followed by attacks of acute colitis occurring every two or three weeks. Radiologic examination revealed the fact that the cecum and a part of the descending colon were bound down by adhesions, and that a small blind pouch had been formed in this part of the intestines. This was relieved by an operation and another radiograph three months later showed the colon in normal position. The colon is to be injected with a metallic mixture before making such a radiograph.

Technic for Radiologic Examinations of Stomach and Intestines.—Hulst[4] has elaborated a technic for the radiologic examination of the stomach and intestines which is an abridgment of Holzknecht's[5] and is based also upon Rieder's[6] work. The patient, whose stomach is known to be empty, stands in front of the x-ray tube, which is enveloped in an opaque shield with a diaphragm provided with a small lead disk, which is in a direct line with the focus of the tube. The shadow of this disk, as the tube is moved to different positions, indicates

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[1] Deutsch. Med. Woch., August 3, 1905.

[2] Wein. klin. Woch., June 8, 1905, p. 621.

[3] Münch. Med. Woch., March 3, 1908.

[4] Am. Quarterly of Roentgenology, Jan., 1907.

[5] Mitteilungen o. d. Lab. f. Radiolog., Diag., and Therap., vol. i, No. 1.

[6] Fortsch. a. d. Geb. d. Roentgen., vol. viii, No. 3.

the normal ray, or a regular orthodiagraph may be used. The patient swallows a Seidlitz powder in two parts, the soda first and then the acid, each dissolved in half a glass of water. The position of the right and left domes of the diaphragm are noted by fluoroscopy, penetration No. 5 or 6 Walter. Now, as the stomach fills with gas it looks transparent, like the lungs. This light area may be traced through a series of radiographs and is called the *Magenblase* (German equivalent for stomach-bubble). The amount of upward displacement of the diaphragm by this gas is noted, and then the patient is given a bolus containing 25 gr. of bismuth subnitrate. If the patient is turned 45 degrees to either side the opaque mass may be watched as it passes down through the esophagus. A swallow of water may be required to assist this. Looking at the patient from directly in front the *Magenblase* is seen to become narrower and to lengthen downward. The bismuth does not at once pass to the lowest part of the stomach, but it may require pressure upon the abdomen to cause it to do so. A mark indicating the lowest part of the stomach is then placed upon the skin. The patient then swallows 180 gr. of bismuth subnitrate in

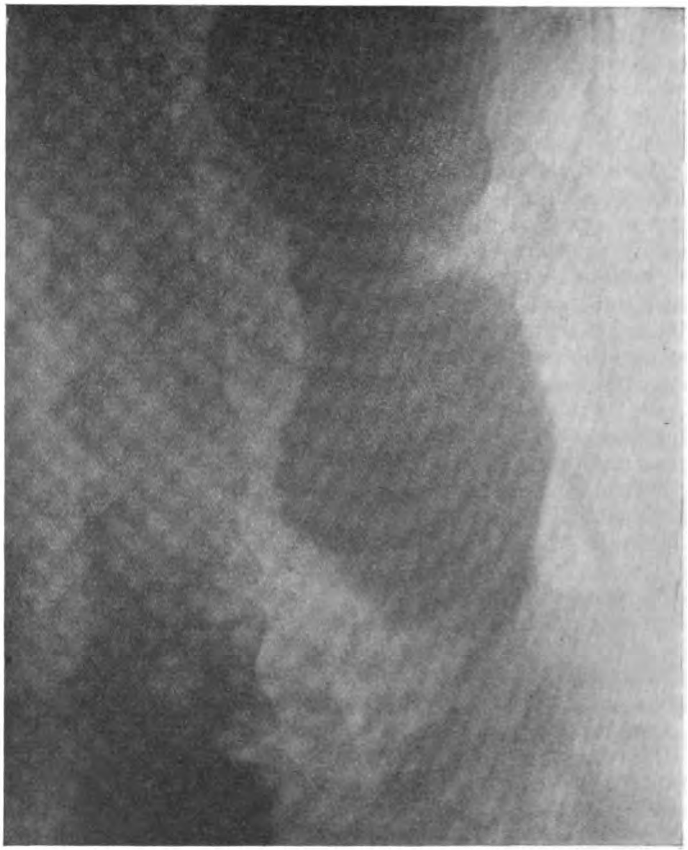

Fig. 673.—Vertical stomach; hour-glass adhesions (case of Dr. R. C. Kemp).

3 ounces of water, and this is watched with the fluoroscope as it passes down into the lowest part of the stomach. The patient then lies down while he swallows an ounce of bismuth subnitrate in a pint of milk. The opaque substance now fills the entire stomach, and fluoroscopy or radiography is practised from different directions; for instance, a radiograph is made with the plate under the abdomen and the tube over the back, in a direct line with the umbilicus.

Neither a dorsoventral or ventrodorsal radiograph, made with the patient lying upon the plate face up or face down, shows whether there is gastroptosis or not. If it is present, these two positions tend to correct it.

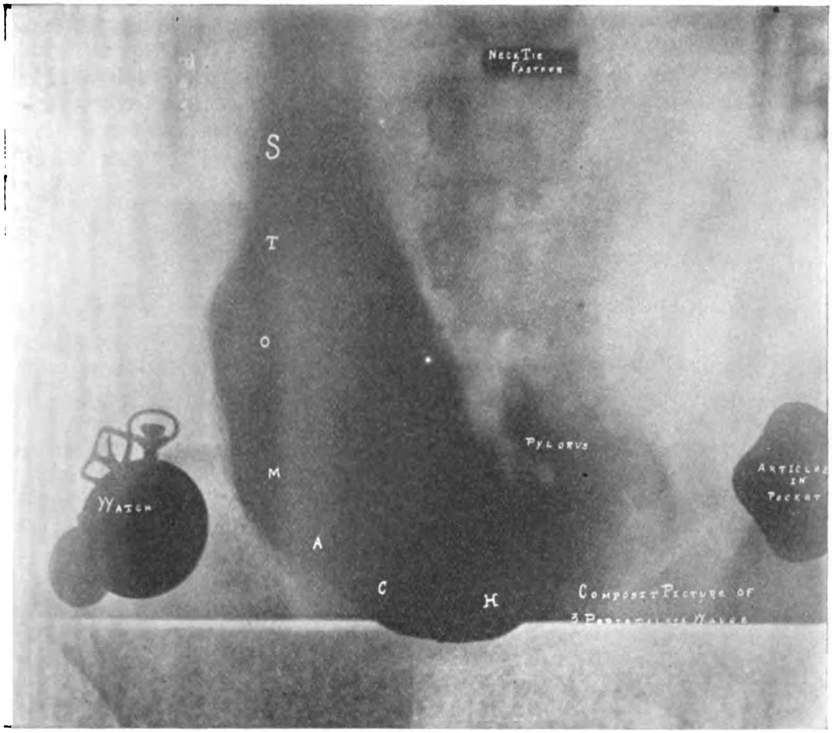

Fig. 674.—Radiograph of stomach through the clothes.

What they do show is the size and shape of the stomach, whether there is any constriction, and sometimes whether there is a tumor of the stomach wall. This was shown in one of Holzknecht's cases by a portion free from the bismuth opacity, the tumor projecting into the cavity of the stomach and displacing just so much of the bismuth.

One of Hulst's cases of gastroptosis showed in the horizontal dorsoventral radiograph that the caudal pole of the stomach was at the level of the fifth lumbar vertebra, while in the erect position the caudal pole was behind the symphysis pubis.

A radiograph made six hours after the ingestion of the bismuth will show whether it has passed out of the stomach, and will thus test the motor efficiency of the organ.

Later radiographs will trace the bismuth through the intestines.

Use of the Duodenal Tube in Radiography.—An elongated stomach-tube, with a perforated metal ball at the end, is passed into the stomach after swallowing a glass of milk and water. The patient lies on his right side and after a time the tube passes into the duodenum. Then a rubber ball surrounding the metal end of the stomach-tube may be inflated and will arrest the passage of a small bismuth meal through the duodenum in such a manner as to secure an accurate radiograph of this portion of the intestine. The duodenal ball is deflated and the apparatus is drawn out through the mouth. Gross and Einhorn and Cole and Skinner were the pioneers in this method.

Intensifying Screens in Gastro-intestinal Radiography.—There is no need for great detail in these pictures, and there is every reason for desiring to make short exposures. A transformer current of 90 kilovolts and about 50 ma., producing an intensity of 1 Tousey, will make these with an exposure of less than one-quarter second if a good intensifying screen is used. A plate without an intensifying screen requires fifteen seconds; unless extremely powerful currents are employed, when the exposure may be reduced to a single second.

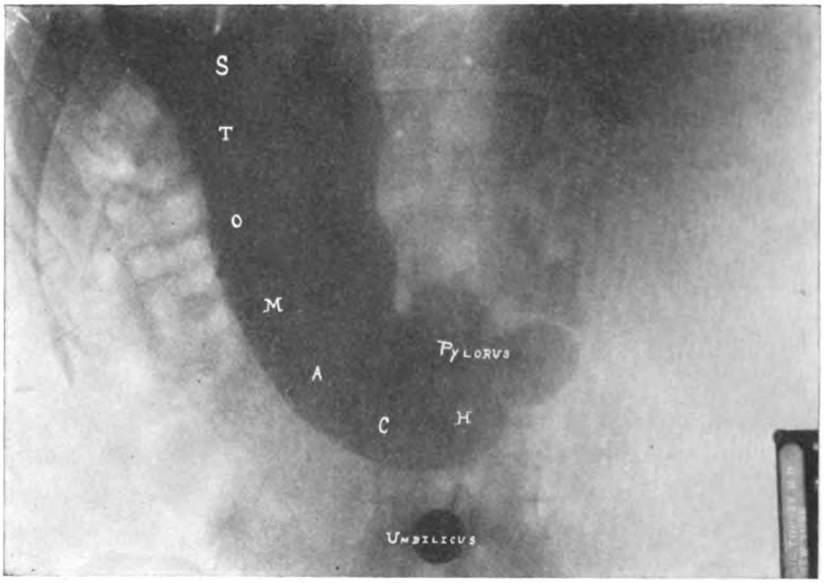

Fig. 675.—Radiograph showing normal position of the stomach; same case as Fig. 671.

The Author is Opposed to Cinematography of the Stomach.—Such a rapid series of pictures can only be made upon a film, and films require a longer exposure than the fastest plates. Modern *x*-ray apparatus are so powerful that with the most rapid plate and the best intensifying screen a good picture may be made with an exposure of one-twentieth to one-fifth second, or with a film and an intensifying screen one-fifth to one second. But to do this the same amount of x-radiation traverses the body as if a 12-inch induction-coil were used with the same film and intensifying screen and an exposure of four to twenty seconds. Twenty or forty exposures of one-fifth second each with the strongest current radiance does not seem as risky as twenty or forty exposures with the radiance formerly employed, but such is the case. All the necessary information may be safely gained with a comparatively small number of the most sensitive plates reinforced by the best intensifying screen.

Cole's arrangement for radiocinematography comprises a lead box like a camera, in which the film extends from one roller to the other under an intensifying screen, against which the film is pressed at the moment that the current is turned on. The current is broken automatically after a certain fraction of a second, the pressure upon the film against the intensifying screen is released, and another portion of the film unwound. The pictures, of course, are the full size of the stomach, and reduced copies are made upon a strip of cinematograph film.

It is not practicable to make cinematograph pictures directly with a camera pointed toward the fluoroscopic screen as if that were a moving object. The exposure would have to be so long as to give a blurred image of any moving object.

The author is strongly opposed to the use of the fluoroscope either for examination or for the purpose of determining the most favorable position or time for making the radiographic exposure. It is safest for the operator to have him stand behind a screen of sheet-lead or of lead-glass and, preferably, not in a direct line with the x-ray, but to one side, where he can view the fluoroscopic image in a mirror. The fluoroscopic screen may be vertical with the patient standing before it, or it may be horizontal under the table upon which the patient lies. Safe as it may be made for the operator, an element of danger remains for the patient, in the fact that while the x-radiance may be reduced to a weaker strength than used in radiography any fluoroscopy takes a tremendously longer time, and could only be made relatively safe by determining beforehand the danger limit and using a time-switch to turn off the current long before that had been reached. Not alone the possibility of dermatitis, but of disturbance of blood, metabolism, and excretion must be taken into account in determining the safe time of exposure. Accidents with the fluoroscope were frequent in the early days when used in the search for foreign bodies in the hand or for the examination of the knee and other joints. The extension of its use to the stomach, where a much stronger radiation is required, is additionally dangerous.

IMPORTANT LITERATURE UPON RADIOLOGY OF STOMACH AND INTESTINES

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Wilms, Cœcum mobile und chronische Appendicitis. 40, Kongr. der D. ges. f. Chirurgie, Berlin.

URINARY CALCULI

Urinary calculi may very often be shown in a radiograph. If they do not show in a good picture it is not positive proof that they are absent, for some of them, consisting of friable pure uric acid, have such slight density that they make no contrast with the tissues. The denser varieties, even if quite small, show well in any picture in which the detail of the vertebræ, their bodies, spines, and transverse and vertical processes, can be seen together with the last ribs and the quadratus lumborum and psoas muscles. To obtain such a picture without danger to the patient requires the most perfect technic and first-class apparatus. One should hesitate to attempt such a picture until he has acquired such practical experience with the *x*-ray that he is able to secure excellent radiographs of less difficult parts with a moderate strength of current and with short exposures. The first case that one colleague attempted was exposed for six minutes, nothing on the photographic plate; and again for sixteen minutes without any result except a severe burn. To secure a good picture of this region every time, instead of occasionally as a sort of accident, it is necessary to be able to properly excite the *x*-ray tube. Every word in the chapter on general radiographic technic should be known by the operator and verified and mastered by repeated experiment. The effort should not be to take radiographs in the shortest possible time, but rather to take the best possible radiographs and in the safest possible way. Calculi may be in the pelvis of the kidney, in the ureter, or in the bladder, and two different positions of the patient are desirable. For those in the kidney, or in the part of the ureter above the brim of the pelvis, the patient should be lying upon his back with the plate (measuring 14×17 inches) placed transversely beneath him from the tenth dorsal vertebra to just above the trochanter. The patient's knees should be raised and the feet rest against some support, the effort being to bring the lumbar vertebræ into contact with the plate.

A large fat person is very much more difficult to radiograph than a small thin person. The difficulty does not appear to be so much an impenetrability of the body, as a very, much increased diffusion of the *x*-ray, or, more accurately, an increased production of secondary rays. The use of a diaphragm and cylinder to cut off the secondary rays from the *x*-ray tube, with or without compression, is of great service in overcoming this difficulty.

The thickness of abdominal tissue through which the *x*-ray must penetrate may be diminished in three different ways: One is by the use of an air-filled bladder, which is pressed upon the abdomen by a belt passing over it (Caldwell), another is by the use of the compression cylinder (Albers Schönberg), and the third is by the use of the author's board compressor.

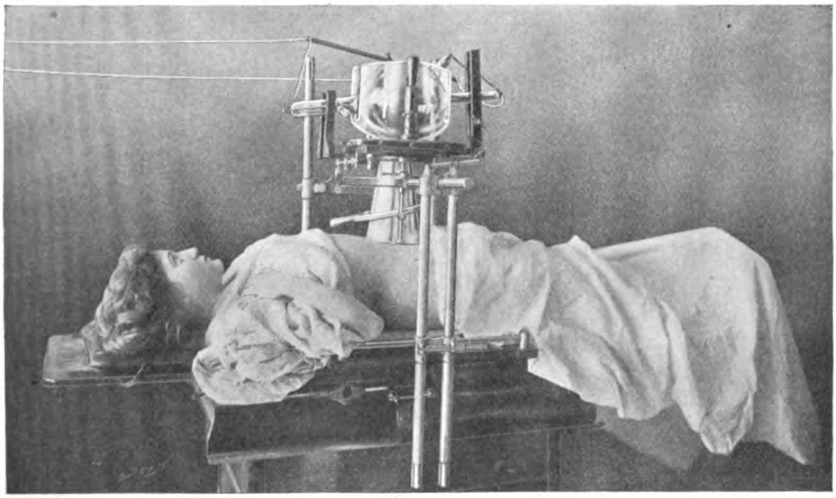

Fig. 676.—Renal radiography with a compression cylinder. The knees should be drawn up and a pillow placed under the shoulders as in Fig. 677.

The compression cylinder (Fig. 677) produces an excellent picture, but one not more than 6 or 8 inches in diameter, and hence a single picture does not give conclusive results in cases in which the position of the calculus or even its very existence is not known.

The Board Compressor.[1]—Equally good detail is obtained with the author's board compressor, and it has the very great advantage of producing a picture the full size of a 14×17-inch plate. It consists of a board of white wood ⅛ inch thick, 9½ inches wide, and 18 inches long, which is reinforced at either end by cross-pieces $\frac{5}{16}$ inch thick. The cross-pieces are 2 inches wide, are beveled toward the middle, and are glued, not nailed, on. Two holes are bored through each of

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[1] Tousey, Louisville Medical Progress, November, 1904.

the reinforced ends for cords passed under the table. The board is pressed tightly across the abdomen (Fig. 677), making a reduction of 2 or 3 inches in the thickness through which the x-ray must pass, and is itself perfectly transparent to all but the softest rays. As these rays are the ones which produce dermatitis the board compressor furnishes an element of safety.

The *compression band* with an inflated rubber ball is easily and quickly applied (Fig. 677).

Heavy tungsten target tubes are necessary for this work.

The tube must be excited in such a way as to produce a brilliant radiance, as viewed with the fluoroscope, and the vacuum ought to be medium, resistance about 3 or 3½ inches, and radiometer No. 6 or 7 Benoist. The distance from the target to the plate should be 18 for a small and 25 inches for a large person. A primary current of 15 amperes, with small self-induction, a Wehnelt interrupter, and an interrupted exposure lasting one hundred or one hundred and fifty seconds is absolutely safe, and with correct technic will produce an excellent radiograph. Eighteen amperes, producing an intensity of $\frac{1}{14}$ Tousey, will require an exposure of thirty seconds. The extremely

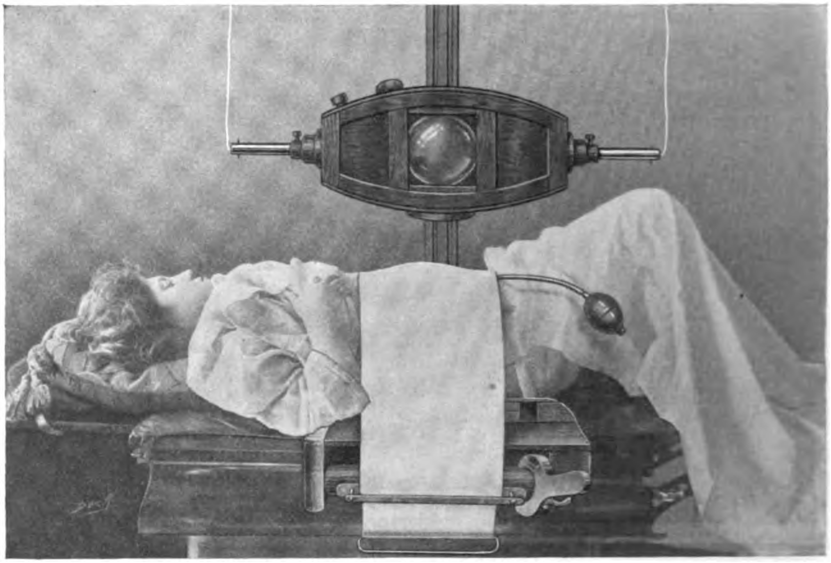

Fig. 677.—Renal radiography with compression band, under which is an inflated rubber bag. The author's plate tunnel enables one to put the plate in exactly the right place without moving the patient and to change it for stereoscopy.

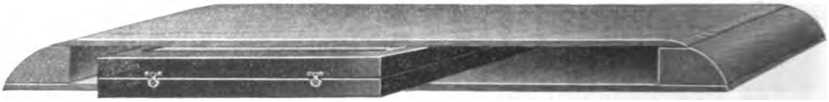

Fig. 678.—The author's "plate tunnel." Strong enough to sustain the patient's weight, but transparent to the x-ray. So large that the plate, in its holder with or without an intensifying screen, may be positioned without moving the patient.

powerful transformer currents, described on p. 721, permit of exposures of about one second. The current should be shut off during a long weak exposure in time to prevent the tube from becoming overheated and after a minute's pause turned on again. It will be remembered that there are two dangers from overheating—the anticathode may be burnt through or the vacuum may become excessively low. It is wise to have another tube in readiness and to watch the behavior of the tube in use. If the tube becomes useless the second tube should be substituted, taking care that its anticathode shall be at exactly the same point, directly above the umbilicus, as the first. For the bladder and the portion of the ureter below the brim of the pelvis the patient lies flat on his back, with the limbs extended, and sufficient cushions under his back to tilt the pelvis somewhat forward. The anticathode should be vertically above a point 3 inches below the umbilicus. In this position the rays pass down through the pelvic canal, and any calculus present is seen free from the shadow of the bones. The distance of the tube from the plate, the degree of vacuum, and length and intensity of the exposure are the same as for renal calculi. The compression board is used. Following the author's almost invariable practice in radiography a shield of *x*-ray metal (tin and lead) is placed behind the plate to shield it from secondary rays arising from the wood or other parts of the table or from different objects in the room.

Riddel[1] uses the fluoroscope as a preliminary to radiography in examining for urinary calculi, but this is extremely dangerous.

The plan of having the patient lie face down upon a canvas stretcher or thin board table, with the tube underneath the abdomen, enables one to make a fluoroscopic examination for renal or ureteral calculi. The fluoroscope is held over the patient't back. The tube may be held by the orthodiagraph, or it may be completely enclosed in an opaque shield, such as Ripperger's. Using the latter with the largest diaphragm and the anticathode at a distance of 25 inches from fluorescent screen, the whole of both kidney and ureter regions and the bladder become visible at once. Any large calculus may be discovered by an eye trained to this phase of fluoroscopy, and may be subjected to more exact scrutiny with a smaller diaphragm or cylinder, or with the author's cellular diaphragm. The protective shield prevents injury to the operator's limbs or genitals, and, if the room is entirely darkened and the fluoroscopic screen covered by a sheet of lead-glass, his face and eyes are also protected. A radiograph may be made of the whole region, or a smaller one, with a diaphragm or cylinder, may be made of a stone located by fluoroscopy. The dangers to the operator are so great that even these precautions will not make it safe to use frequently.

The danger to the patient must be remembered, and, if the localization of a calculus with the fluoroscope is evidently going to take more than a very few seconds, the operator should stop and at once proceed to make a radiograph.

This prone position produces more or less natural compression of the abdomen, and the compression may be increased by placing an air-bag of some kind upon the table under the abdomen. Compression by the compression cylinder is not practicable in this position.

Locations in Which to Look for Urinary Calculi.—Renal calculi are usually found near the angle below the twelfth rib and external

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[1] Glasgow Med. Jour., Feb., 1906.

to the border of the spine. If they are much below this region, it is because of displacement of the kidney, and suspicious shadows beyond the tip of the twelfth rib are almost always of intestinal origin.

Ureteral calculi are most often found below the brim of the pelvis. The course of the ureter may be indicated by a line starting 1 inch internal to the spine of the pubis and extending to the sacro-iliac synchondrosis. But this position might be misleading in case of a calculus sacculated at some distance from the ureteral lumen (Tilden-Brown).

A radiograph made with the tube over a point midway between the umbilicus and the symphysis pubis, and with the anticathode about 10 inches from the surface of the abdomen, will avoid casting the shadow of the ureters upon the sacrum, where it might be difficult to recognize the shadow of a stone.

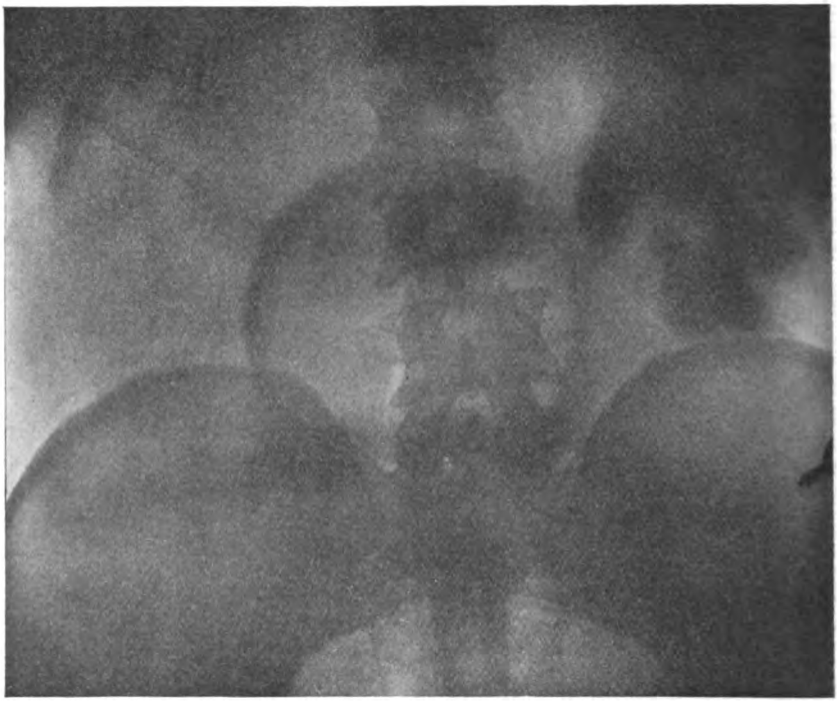

Fig. 679.—Use of Tousey's radiating cellular diaphragm in radiography of renal calculi. Weight of patient, 158 pounds. Induction-coil, 18 amperes; sixty seconds in a divided exposure. Lumiere *x*-ray plate. This apparatus has been abandoned because it required fluoroscopic adjustment and was dangerous to the operator.

Among 9 cases of ureteral calculus reported by A. T. Cabot[1] the stone was lodged at the junction of upper and middle-thirds in one case, 2 were lodged at the lower part of the middle third, and 6 in the lower third of the ureter.

In Baetjer's 351 cases examined for urinary calculus only 3 cases revealed a ureteral calculus lying above the brim of the pelvis.

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[1] Boston Med. and Surg. Jour., 1905.

The Use of the Cylinder and Diaphragm in Radiography of Renal and Ureteral Calculi.—A small cylinder, 3 inches in diameter and 7 inches long, extending from the surface of the patient's body to the localizing shield, or opaque box enclosing the *x*-ray tube, makes the distance from the anticathode to the photographic plate about 25 inches. The diameter of the picture is 6 inches, and a really wonderful improvement in definition is obtained compared with the results when no diaphragm at all is used. Careful study will enable one to secure a picture of the exact region of the kidney, an 8 × 10-inch plate being required. By applying the cylinder at first a little to one side of the median line, and then to the other, both kidney regions may be radiographed without exposing the same tissues twice to the *x*-ray. A single radiograph with the same small cylinder in the median line and 2 inches above the symphysis pubis, and tipped a little downward, will show the whole cavity of the pelvis and reveal calculi in the bladder or in the pelvic part of the ureter. One made with a cylinder 5 inches in diameter in the median line, 3 inches above the symphysis pubis, will show the middle portion of both ureters.

Stereoscopic radiography may be occasionally used in the differential diagnosis of renal calculi. Filling the bladder and rectum with oxygen gas still further increases the clearness of the image.

It is rather important to make certain that the patient has not been taking bismuth for a few days before such an examination. This would cause a shadow which might be mistaken for that of a calculus.

Dense cicatrices in the kidney have been seen by Baetjer to cause suspicious shadows similar to those of calculi.

Dark shadows on the plate or light areas in the print, presenting a size, shape, and position suggestive of urinary calculi, must not be mistaken for them. They may be due to one of two different causes: first, an imperfection in the plate; second, a collection of gas in the rectum or some other part of the intestines. These shadows represent areas of reduced resistance to the *x*-ray, and cannot, therefore, be due to calculi, which, of course, cause increased resistance.

The last ribs, the crest of the ilium, the transverse processes of the lumbar vertebræ, and the edge of the psoas muscle should all be clearly defined in a radiograph to fit it for the diagnosis of urinary calculi.

Penetrability of Different Kinds of Calculi.—The order of penetrability by the *x*-ray is: 1, Biliary calculi; 2, uric acid calculi; 3, phosphatic calculi; 4, calcium oxalate calculi.

Those least permeable, like the calcium oxalate calculi, cast the deepest shadows and are the most easy to detect.

Uric acid calculi cast faint shadows, but can almost always be detected in a successful radiograph. Phosphatic and calcium oxalate calculi cast dense shadows, and can always be seen in a successful radiograph unless they are very small. A calculus small enough to be passed in the urine may escape detection by the *x*-ray, especially if the patient is large or stout.

The order of permeability corresponds fairy well with the specific gravity of the different calculi.

Cystin and xanthin calculi have shown perfectly well in a number of radiographs by Morris.[1] This may be due to the fact that many of these calculi contain calcium, magnesium, and ammonium phosphate, and they will contain 25 per cent. of sulphur.

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[1] Lancet, July 21, 1906.

Phleboliths.—These small concretions are very apt to occur in the veins of the pelvis, and can sometimes be seen in a radiograph. Their shadows are more definite and their edges are more sharply defined than those of a calculus, and they are almost always very small. They lie close to the line of the ureter at or below the brim of the pelvis. In cases of doubt another radiograph should be made with a ureteral catheter in position. The phlebolith will be found to the outer side of the catheter.

A soft flexible ureteral catheter has been devised by Fenwick, and has also been used by Howard A. Kelly for cases of this kind. It contains a certain percentage of bismuth, and is safer to use than a catheter with a metal stylet. A catheter into which a certain amount of metallic mercury has been poured is equally good for this purpose, but is not so simple as the catheter impregnatd with bismuth.

The Ureteral Catheter in Radiography.—A ureteral catheter rendered opaque as above may be introduced as an aid in the radiographic diagnosis of ureteral and renal conditions. Damsky[1] used this method successfully in 2 most interesting cases. In one patient a simple radiograph had shown a kidney-shaped body. The radiograph, made with a ureteral catheter and stylet in position, showed that these did not pass into the kidney-shaped body. It was concluded, therefore, that this was not the kidney, and upon operation it was found to be an ovarian cyst with an extremely long pedicle. The other case was that of a woman with a ureteral fistula following the removal of a uterine fibroid. A radiograph, made with catheters in both ureters and the fistula, showed which ureter had been opened and at what level.

A ureteral catheter containing metal wire will show in a radiograph. Bransford Lewis[2] reports a case in which three ureters were demonstrated in this way.

The ureteral catheter will also aid in deciding whether a shadow on the plate is due to a calculus or to something outside of the ureter. Fenwick[3] reports cases in which the radiograph showed bodies apparently in the ureter, but a second radiograph with a ureteral stylet showed that such was not the case. The operations showed that the shadows were those of calcified lymphatic glands or arteries.

Technic of Ureteral Catheterization (Dr. Ralph Tousey, Personal Communication).—The catheters are sterilized by washing with green soap and water, placing them in $\frac{1}{2000}$ bichlorid of mercury for an hour or two, then in 2 per cent. boric-acid solution. They are dried and kept dry. If they are to be used soon keep them in boric-acid solution. The stylets may be boiled or passed through an alcohol flame and kept temporarily in boric-acid solution. The metallic instruments are sterilized by washing in alcohol. Local anesthesia is secured in the female by filling the urethra with 20 minims of 5 per cent. solution of cocain from a hypodermic syringe without a needle, leaving the solution in for three minutes, and in the male by the instillation of 5 or 10 minims of 1 per cent. solution of eucain in the prostatic urethra. Glycerin is used as a lubricant.

For the Nitze type of cystoscope, for instance, the Brown-Buerger, the patient is in the dorsal position, with the legs supported by crutches.

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[1] Vratchnebnaia Gazeta, July 9, 1905.

[2] Medical Record, Oct. 6, 1906.

[3] British Med. Jour., 1906.

Six ounces of 2 per cent. boric-acid solution is injected into the bladder through a flexible catheter, which is withdrawn, and then the catheterizing cystoscope is introduced. The perforated caps of the latter are already provided with the two catheters, the other ends of which are held at a higher level by the patient or nurse. The orifice of one ureter is to be sought obliquely outward and backward 1½ inches distant from the urethra, and a number of blood-vessels will be seen to radiate from it. Push the corresponding catheter in until its tip is seen, and further, until the tip disappears beyond the field of vision. See the ureter, bend up the catheter with the lever provided for the purpose until the tip of the catheter is seen; push the entire instrument toward the catheter and the catheter will probably enter the ureter. When in push the catheter a couple of inches further into the ureter, and swing the instrument over to the other side and introduce a catheter into the other ureter. The urine may be collected in two sterile test-tubes for ten or fifteen minutes. Pushing the catheters in, the pelvis of the kidney will be entered at a distance of about 50 cm. from the internal urethral orifice; this will be evidenced by a certain obstruction, also perhaps by the escape of a dram of urine at once instead of the ureteral peristalsis. The capacity of the pelvis is about 2 drams.

The Howard Kelly cystoscope is simply an open hollow cylinder introduced into the air-filled female bladder and directly exposing the ureteral orifice, which appears of its natural size instead of being magnified eight times, as in the Brown-Buerger cystoscope. Patient on her back, with feet in stirrups, cocain is applied, the bladder is emptied by a catheter, the urethra is dilated by passing No. 20 Hanks cervical dilator. Then the knee-chest position is assumed, buttocks on a plumb-line with the calves, thighs a little back of the perpendicular. Draw back the perineum with the finger to allow the vagina to balloon out; in some exceptional cases introduce a rectal speculum for a moment. Introduce a Kelly cystoscope, 25 French, with electric-light attachment. Depress handle, bladder filling with air. Draw out to internal urethral orifice, then push in for 1¼ inch with a lateral deviation of 30 degrees and see the orifice of one ureter.

As a prophylactic after cystoscopy 2 ounces of 2 per cent. solution of protargol are injected into the bladder.

In case of doubt the author makes two radiographs from somewhat different directions. Coincidence of the shadows of the ureteral catheter and foreign body in both pictures shows that the foreign body lies in the ureter.

Development of the plate to show renal calculi. G. Thurston Holland,[1] working with an induction-coil, mercury interrupter, and an exposure of five to twenty seconds with a primary current of 7 amperes and an Ilford x-ray plate, found that six minutes' development was best. The Ilford metol hydroquinone formula was used and the finished and dried plate was not blackened, but white and thin and easily seen through by daylight. The details of the abdominal tissues and the vertebræ and iliac crests should be quite clear. This, it will be seen, is decidedly different from the development commonly given a screen plate of the stomach or intestines containing bismuth, which is so much denser than a renal calculus and where the plate is usually decidedly blackened.

Results in Renal and Ureteral Radiography.—A mistake in diagno-

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[1] Arch. Roentgen Ray, Jan., 1909.

sis is possible in exceptional cases even in the most expert hands, but in general it forms an extremely reliable means of diagnosis.

Brown[1] mentions a case in which the radiograph failed to show a ureteral calculus which could be seen with the cystoscope, and which was subsequently removed by an operation.

Lydston[2] reports several cases of ureteral and renal calculi removed by operation. Some of these were found in the skiagraph, but in fully as many other cases they were not.

The *x*-ray gave negative results in a case reported by Ware.[3] The case was one of contracted bladder, and at a post-mortem examination a stone was found in each ureter close to the bladder.

The late Tilden Brown[4] found that in cases of pure uric-acid stones a negative radiograph was as likely as not to be returned by the radiographer, and this, too, in subjects of favorable proportions and where the intestinal contents are thoroughly removed.

Baetjer[5] reports a successful use of the *x*-ray in practically all of 351 cases examined for urinary calculi.

The author's own cases include a number in which a positive diagnosis of calculus was made from the radiograph. All but one of these are known to have been operated on and the calculi removed. The one case known not to have been operated on made the most beautiful picture of all. The patient was referred to the author by Dr. Leroy Broun, and a radiograph showed a collection of stones, like a bunch of grapes, in the left kidney. Since the pain and tenderness had always been on the right side, a second radiograph was made, placing a distinguishing mark on the right side of the plate. This again showed the group of calculi in the left kidney. The pictures are decidedly different, showing either a different grouping of the calculi or a difference in their position relative to that of the *x*-ray tube. Dr. Broun lost sight of the patient for a number of years because the man was afraid to be operated upon. A radiograph (Fig. 679), made at the end of that time, showed a similar condition.

A curious case of the author's was one in which the radiograph showed a calculus which the operator, Dr. Gallant,[6] found embedded in the mesentery 2 inches from the ureter. It had all the characteristics of a ureteral calculus.

Another case had been subjected to thirteen *x*-ray examinations before being brought to the author by her physician, Dr. W. Travis Gibb. Six or seven of these had been made in England, and revealed a ureteral calculus which had been passed spontaneously. The remainder of the radiographs had been made in America. None of the entire thirteen radiographs showed a renal calculus, although there were well-marked symptoms of such trouble. This kidney was known to be prolapsed and the other kidney had been removed. The radiograph was made in the author's usual manner, without any extra intensity of radiance or extra length of exposure, and revealed the presence of a large renal calculus, presenting two horn-like prolonga-

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[1] N. Y. Med., Acad. G. U. Section, Oct. 17, 1906; Jour. Am. Med. Assoc., Dec. 15, 1906, p. 1204.

[2] Jour. Am. Med. Assoc., 1906.

[3] N. Y. Med. Jour., March 31, 1906, p. 684.

[4] Ibid., p. 683.

[5] Amer. Quar. of Roentg., Jan., 1907.

[6] N. Y. Med. Jour., March 31, 1906, p. 684.

tions downward. Smaller pieces were visible around it. The stones were removed by Dr. Gibb a day or two later, and were found to correspond in shape with the radiographic image.

Should the Surgeon be Given the Radiograph or Should He Simply be Given the Radiologist's Report of His Examination?—The last case is one in point. The radiologist who had made the last examination previous to my own had refused to let the surgeon have the radiograph, but simply stated that it showed that no stone was present. The subsequent result showed that this opinion was incorrect, and that if it had been acted upon the patient would have been left to suffer from this very painful condition.

It is, I believe, the opinion of a majority of the active members of the American Röntgen Ray Society that the radiologist is to give his opinion and not a picture from which the surgeon can make his own diagnosis. This is on the theory that the radiograph requires interpretation by a specialist.

My own feeling is that the surgeon should receive the picture as well as the radiographer's full explanation of it and his diagnosis. The surgeon should have the opportunity to become familiar with radiographs of the different conditions which he is called upon to treat, and should be able to judge of the quality of the picture. If it is a mere foggy daub, when he knows that a good radiograph should show the lateral processes of the lumbar vertebræ, he is not obliged to take the radiologist's diagnosis and run the risk of performing a serious operation uselessly or of neglecting to perform an operation in a case which requires it.

The surgeon will doubtless accept the radiographer's diagnosis in almost every case, but he should have every opportunity of knowing whether this opinon is based upon a successful radiograph or not.

In some cases the surgeon has made a special study of the radiographic appearance of a particular class of lesions, and his opinion may be even more valuable than that of the radiographer. The author has learned a great deal from friends who have sent him cases to be radiographed because they have not the time to devote to the technic manipulation of *x*-ray apparatus.

In one case of the author's two plates were exposed at the same time and both showed excellent detail. One showed an image like that of a calculus somewhat below and external to the region of the kidney. The image did not show on the other plate, and the probability seemed that it was due to some defect in the first plate. Dr. Douglas H. Stewart operated, however, and found a calculus in the position indicated by the first plate.

A considerable number of cases have been examined by the author in which the radiograph showed no stone in the kidney or ureter. As far as he knows, none of these cases have been operated on and, therefore, it is impossible to say whether the negative diagnosis was correct in all of these or not.

Chas. Lester Leonard and Lewis Gregory Cole have reported a large number of cases examined by them for renal and ureteral calculi with excellent results. Leonard formerly gave a long exposure, four or five minutes, with a moderate intensity of radiation, but now uses a transformer and an exposure of only a few seconds. Cole uses a short exposure, about half a minute, with great intensity.

As to the degree of penetration, Caldwell uses a ray with which the bones of the hand appear gray. (The use of the hand as a radiometer is a most dangerous practice.)

Some of the author's best radiographs of the pelvis and lumbar region have been made with a penetration of only No. 4 Benoist, with which the bones of the hand would appear almost black on fluoroscopic examination.

One case was examined for calculus, and the very distinct image of the kidney was regarded as sufficient evidence, taken together with the history of the case, to require an exploratory operation. The operator, Dr. Tucker, found a prolapsed kidney in a state of chronic inflammation, requiring removal of the entire organ. There were no calculi and no calcareous foci.

HYDRONEPHROSIS

This disease produces an abnormal appearance in the radiograph. An area of opacity may be seen to begin in the kidney region and extend downward and perhaps inward from it. Its regular, sharply-defined, convex border and large size are its chief characteristics. These may not enable one to make more than a probable diagnosis of hydronephrosis, but they do exclude renal calculi or biliary calculi (as the sole lesion), tuberculosis of the kidney, or intestinal obstruction.

Report on the Radiographic Findings in a Case of Hydronephrosis.—The patient was sent to me through the kindness of Dr. Beaman Douglas. Gall-stone disease was suspected from the symptoms of attacks of pain and tenderness and from the presence of a tumor in the gall-bladder region. A radiograph was made after an ordinary dose of Rochelle salt, and another a few days later, after very thorough purgation by Hunyadi water and fasting for twenty hours. The following is an abstract of my report on the radiographs:

"The two pictures are practically identical. They show the absence of any renal, ureteral, or vesical calculus, and they show an area of quite dense opacity, extending downward and inward from the right lobe of the liver to the median line at the level of the crests of the ilia. The right-hand border of this area of opacity is very sharply defined, and forms an unbroken line, which makes the right side of the abdomen in the radiograph contrast greatly with the left side. We see on the left side a more or less irregular and broken border to the shadow of the abdomen. The area of opacity on the right side obscures the lower ribs on that side and also a part of the vertebræ. A mass of gall-stones would not be expected to cast so decided a shadow, and certainly not one with such a clearly defined border. The opacity would indicate the presence of either a large sac of fluid or of a solid tumor. There appears to be very little doubt as to the necessity of surgical exploration in this case. It cannot be stated whether there are any gall-stones present at all, and they certainly do not form the bulk of the swelling which is felt on abdominal palpation."

The operation, performed by a surgeon in Portland, Maine, evacuated a large sac of fluid, which at first appeared to be a retroperitoneal cyst, but from which urine began to flow in a few days, proving that the trouble was hydronephrosis.

PYELOGRAPHY

Volcker and Lichtenberg[1] pass a ureteral catheter into the kidney and inject a warm (5 per cent.) solution of collargol (a silver compound) into its pelvis. The size and shape of the pelvis of the kidney can then be shown in a radiograph. The method is suggested for the diagnosis of dilatation and of deformity of the ureter.

PERINEPHRITIS

The x-ray gave negative results in a case of paranephritic sclerosis operated upon by Berg.[2]

HEMORRHAGIC NEPHRITIS

Hemorrhagic nephritis was present in 2 cases reported by Wiener.[3] The radiographs showed no abnormal appearance of the kidney, ureter, or bladder.

RENAL TUBERCULOSIS

Tuberculosis of the kidneys, according to Brown,[4] presents radiographic appearances of diagnostic value. Such a kidney casts a well-marked shadow. In one of Brown's cases the x-ray showed a shadow suggestive of renal calculus, and an operation showed that the kidney was tuberculous and filled with a putty-like substance. J. Bayard Clark[5] and others have reported cases of tuberculosis of the kidney which were diagnosed by radiography, combined with cystoscopy and cryoscopy.

A radiograph of urine in a case examined for Dr. E. L. Keyes, Jr., gave positive indications of the character of the lesion.

RADIOGRAPHY OF VESICAL CALCULUS

Two positions are available. One is with the patient face down upon the plate and the tube in the median line at a lower position, so that the rays will shine obliquely upward through the pelvis and prevent the shadow of the sacrum from filling up the entire image of the pelvic canal. In the other position, the patient lies face up upon the plate, and the x-ray tube is in the median line, about 3 inches above the symphysis pubis, the anticathode being at a distance of 17 inches from the plate if no cylinder diaphragm is used, and about 24 inches if this apparatus is used.

The rays traverse the pelvis in the same line in both cases, but in opposite directions. The idea is to show the cavity of the pelvis as free as possible from the shadow of the sacrum. The author places the plate behind and the tube in front, but some others prefer the ventral position, on the theory that it brings the plate nearer the bladder and consequently nearer the stone. As it is better to have the bladder empty, and as the stone is almost always near the neck of the bladder, this reasoning does not seem exactly correct.

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[1] Münch. Med. Woch., Jan. 16, 1906.

[2] N. Y. Med. Jour., Aug. 18, 1906.

[3] N. Y. Acad. Med. Genito-Urinary Section, Oct. 17, 1906; N. Y. Med. Jour., Dec. 15, 1906, p. 1204.

[4] Ibid.

[5] Med. News, Dec. 9, 1905.

The author's cellular diaphragm gives clearness of definition through this thick portion of the body better than in any other way.

The penetration should be about No. 6 Benoist, and an intensity of $\frac{1}{14}$ Tousey and an exposure of thirty seconds will be required with a coil. A shorter time will give a good picture, but one lacking a little in density. This intensity may be produced by a tube excited by a 12-inch induction-coil with 18 amperes of primary current, supplied by the 110-volt direct current passed through a Wehnelt interrupter, but not using any rheostat resistance. Less intensity, such as $\frac{1}{20}$ Tousey, would require an exposure of two or three minutes, and would be generated by a 12-inch induction-coil with a Wehnelt interrupter, 110-volt direct current, and a primary current of amperes. Transformer currents of 25 to 50 ma., producing an intensity of from $\frac{1}{6}$ to 1 Tousey, require an exposure of from one to ten seconds.

Intermediate intensities produce a vesical radiograph with an exposure between these two extremes.

The rectum and bladder contents should be evacuated, and a much clearer image will be obtained if both these cavities are filled with oxygen gas.

A case has been reported in which the radiograph, made in the ordinary way, did not show a small stone, which was clearly depicted on a photographic film held in the vagina, just as radiographs of the teeth are made upon a film held inside the mouth.

The stones, shown in one of the author's cases, had not been discovered when a Bottini operation for prostatic hypertrophy was performed two years previously, and consequently no improvement had followed the operation. The patient, a man of sixty-five, was sick in bed, having his bladder irrigated five or six times a day, and suffering great pain. A sound failed to discover any stone two weeks before the *x*-ray examination. The radiograph showed two large calculi, which were removed at an operation by Dr. Buck Carleton. He found that the stones were of a putty-like consistence, which accounted for the impossibility of detecting them by ordinary means of examination. Since the operation the old gentleman is able to run up and down stairs and rode 100 miles on horseback in one day a year later. The *x*-ray has actually saved this man's life.

Vesical calculi are usually made up of oxalates or phosphates, sometimes having a nucleus of uric acid, and are usually of considerable size.

Moseley[1] prefers to have the patient lie face down on the plate, so as to bring the bladder nearer the plate.

The bladder and rectum should be empty.

The bladder and rectum may be filled with oxygen gas, but this is not entirely free from danger, and Saenger[2] reports a fatal case.

An encysted calculus in the lower posterior wall of the bladder was found by means of a radiograph by Menges, and removed by Holmes[3] after systematic exploration with a searching sound under general anesthesia had failed to discover it. It was completely encapsulated.

In cases examined for vesical calculus the kidneys and ureters should also be radiographed. Many vesical calculi originate in the kidney, and it is wise to see whether new ones are forming.

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[1] N. Y. Med. Jour., March, 1903.

[2] Arch. d'elect. med., April 10, 1907.

[3] N. Y. Med. Jour., May 27, 1905.

Beck[1] states that since he has begun to radiograph the kidney as well as the bladder he has found renal calculi in every case of vesical calculus. This observation makes it important to investigate the kidney regions as well as the bladder. Additional observations are required to determine whether such a combination is invariably present.

PROSTATIC CALCULI

A case of this comparatively rare condition, referred by Dr. J. P. McGowan, was readily shown by a radiograph. The patient lay supine upon the plate, the lower end of which was raised to an angle of 20 degrees with the table, and the tube was 4 inches above the symphysis pubis. This was with the idea of securing an image of the calculus not overlapped by that of the pubic bones. This did not prove to be the case, but the calculus was such an enormous one that this makes little difference. In fact, in this picture the image of the stone completely overshadows that of the symphysis pubis. Whether the object could be obtained by placing the tube at a considerably lower level than the symphysis is not known by actual experiment, but it seems probable. If so, the stone would cast an image below the arch of the pubis, but overshadowed by the image of the sacrum and coccyx.

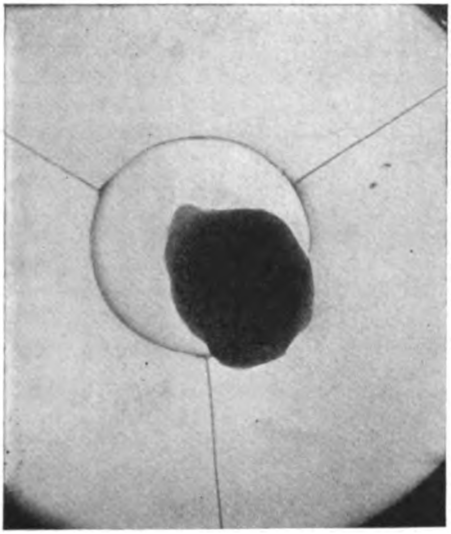

Fig. 680.—Radiograph of prostatic calculus after removal (one-half natural size). Radiating cellular diaphragm employed.

Fig. 681.—Photograph of prostatic calculus after removal (scale of inches for comparison). (Case examined for Dr. McGowan.)

Considering also the possibility that the calculus might be in the bladder instead of in the prostate, the position adopted in making this radiograph seems the most desirable one.

Fig. 680 is a radiograph made with the author's radiating diaphragm of this calculus after removal, and Fig. 681 is an ordinary photograph

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[1] Jour. Am. Med. Assoc., Dec. 23, 1905.

of the calculus held in the hand and with a scale graduated in inches for comparison.

The *seminal vesicles* have been shown in radiographs made after injection of 5 per cent. argyrol solution.[1]

FOREIGN BODIES IN THE PELVIC ORGANS

Foreign bodies in the bladder, vagina or uterus, or the rectum are well shown in a radiograph of the pelvis made with the plate under the patient and the tube over the median line ½ inch above the symphysis pubis.

THE PELVIC BONES

The pelvis is well shown in a picture made as for vesical calculi; but for the sacrum and coccyx especially the pelvis is tilted forward, and the tube is just above the level of the symphysis pubis. The compression board and the cellular diaphragm are used and the other conditions are the same as for renal calculi.

Non-union of the Symphysis Pubis.—This condition as a congenital defect was found in a case of epispadias reported by Mouratoff.[2] The radiograph showed that there was an absence of union between the pubic bones, and that the symphysis was a relaxed membranous barrier.

Separation of the Symphysis Pubis.—This injury is not so very rare as a complication of difficult parturition and can be recognized in a radiograph.

Radiography of the Symphysis Pubis and Its Normal Appearance.—The radiograph may be made with the tube in the median line, and about 1 inch above the symphysis, with the plate under the back of the pelvis. The distance from the anticathode to the plate should be about 17 inches, unless a cylinder diaphragm or the author's cellular diaphragm is used, in which case it should be about 24 inches. An intensity of $\frac{1}{14}$ Tousey and a penetration of No. 6 Benoist will require an exposure of thirty seconds. The radiograph is likely to be a good one, in spite of the fact that the part to be depicted is at a distance from the plate.

Another position is for the patient to lie face down upon the plate, the center of which is under the symphysis pubis. The tube is in the median line and at a lower position, so that the shadow of the sacrum will fall at a higher level than the symphysis. The idea is to have the ray pass along the same line as with the patient in the dorsal position, but in the opposite direction.

Even in a patient sixty-five years old the symphysis shows normally a complete line of separation, and it may happen that in a perfectly normal person of any age the radiograph may show an apparently considerable separation. The knowledge of this fact will enable one to guard against the error of mistaking a normal for a pathologic condition in the symphysis.

Fracture or Dislocation of the Coccyx.—It is suggested by the author that a clearer radiograph of the coccyx and lower part of the sacrum may be obtained upon a photographic film held inside the vagina, just as radiographs of the teeth are made upon films held inside the mouth. A fracture or dislocation of the coccyx could be very

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[1] W. T. Belfield, Jour. Am. Med. Assoc., Nov. 22, 1913, vol lxi, No. 21, p. 1867.

[2] Roussky Vratch., July 20, 1902.

easily and beautifully shown in this way if present, while a mere sprain would not present bony lesions and would be diagnosed by exclusion. The rectum should be empty.

The Lumbar Vertebræ.—Examinations of the lumbar vertebræ for fracture or tuberculosis is practicable and reliable by means of the technic recommended for renal calculi.

Radiography of the Fetus in Utero.—The fetal head shows well when it occupies the lowest part of the uterus, to the practical exclusion of the liquor amnii, but when the head occupies the fundus of the uterus the surrounding fluid produces so much dispersion as to make the radiograph unsatisfactory. The fetal bones are small and almost entirely cartilaginous, so that it is difficult to distinguish them in a radiograph before birth.

The possibility of destroying the vitality of the fetus, or of producing sterility through action upon the mother's ovaries, should deter one from making repeated *x*-ray examinations during pregnancy.

***X*-ray Diagnosis of Pregnancy and of Extra-uterine Gestation.**—A radiograph of the pelvis will be of service in either of these conditions. What is found is apt to be a silhouette of the fetal mass rather than a picture of its different bones.

Lichenstein[1] describes a case of extra-uterine pregnancy with mummification of the fetus. The diagnosis was made by means of a radiograph taken with a medium soft tube without a diaphragm and an exposure of one and three-quarter minutes. The maternal pelvis showed sharply, but the lumbar vertebræ were not so distinct. Over the right rim of the pelvis two fetal extremities were seen, one being a part of the thigh, and the other, at an angle with this, being the leg. The ribs showed as a striped area on the other side of the mother's pelvis. A pelvis presentation was diagnosed, which was verified by operation.

Dermoid Cyst.—This condition showed very well in a case referred to the author by Dr. John M. Keyes.

THE HIP-JOINT

Dislocation, either congenital or acquired, and fractures of the neck of the femur are well shown by a radiograph, but the use of the fluoroscope is not to be recommended.

For a radiograph the patient may lie either prone or supine, the limbs are extended, and the compression band is used (Fig. 682). For a picture of both hips he lies face up, with the plate under the back of the pelvis; the anticathode is directly over the median line, 1½ inches above the symphysis pubis, 15 to 18 inches from the plate. The latter should measure 14×17 inches, and be placed transversely with its center at the level of the trochanters. For a picture of only one hip the plate measures 11 × 14 inches, and is placed longitudinally with its center 1 inch internal to the trochanter. The anticathode of the *x*-ray tube is vertically over the center of the plate, at a distance of 15 to 18 inches from it. The tube should have a heavy target, so as to permit the use of a primary current of 10 amperes or more, and the exposure should be two minutes with 10 amperes ($\frac{1}{16}$ Tousey), or one minute with 15 amperes ($\frac{1}{14}$ Tousey), or fifteen seconds with 25 amperes ($\frac{1}{10}$ Tousey). Transformer currents make it possible to make a radiograph

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[1] Münch. Med. Woch., vol. vi, 8–24.

of the hip in one second without an intensifying screen, but ordinarily five seconds is better. The best, though perhaps not the quickest, pictures are made with a medium low vacuum, resistance 2 inches, radiometer No. 3 or 4 Benoist. Any diaphragm or cylinder will give increased definition for one hip at a time.

Tuberculosis of the Hip.—Tuberculosis of the hip is often shown by the radiograph at an earlier stage than by any other means. The head of the femur may be almost transparent and a portion be absorbed.

Among the signs of tuberculosis of the hip seen in the radiograph may be an unnatural transparency of the head of the femur or of the acetabulum, due to demineralization. Absorption of the articular cartilages would be shown by an unnaturally close apposition between the bony surfaces. Malposition is readily discovered. There may be abscess-cavities or sequestra, the acetabular cavity may be enlarged, or the head and sometimes part of the neck of the femur may have disappeared.

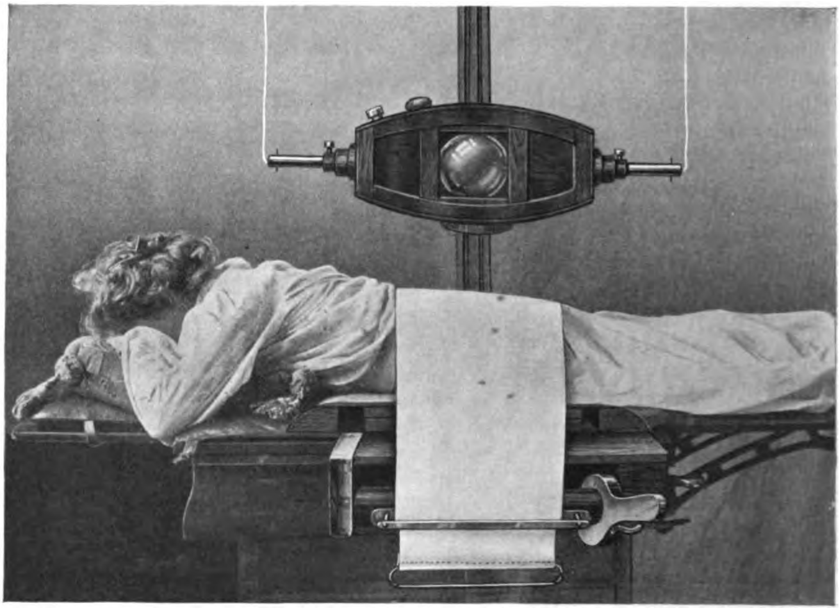

Fig. 682.—Radiography of hip-joint with a compression band and the author's plate tunnel, in which the plate may be placed and changed for stereoscopic pictures without moving the patient (page 956). The author's contact diaphragm should be used in contact with the *x*-ray tube.

Lovett and Brown[1] report the results of radiographic study in 100 cases of suspected hip disease. They examined the collection of radiographs which had been taken at their hospital for a number of years and recorded the results before consulting the clinical histories. The radiographic diagnosis was found to agree with the clinical diagnosis in all but 5 of the cases. The cause of error in 1 case was the presence of an inguinal abscess, blurring the outline of the head and neck of the femur in such a way as to cause it to be mistaken for tuberculosis.

[1] N. Y. Med. Jour., Jan. 28, 1907.

Two cases with normal radiographic appearances proved to have had hip disease; one for six months and the other for a year. All the other 18 cases, which gave a normal radiographic appearance, were also diagnosed clinically. Some of these hips showed merely incidentally upon plates made for stone in the bladder or other troubles.

Sixty-one cases were diagnosed from the radiographs as typic hip disease, and this was confirmed by the clinical histories, both before and subsequent to the making of the radiograph.

The radiographic appearances in an early stage, when the only symptoms are sensitiveness and muscular spasm, may not be perceptibly different from those of a normal hip.

When limitation of motion due to spasm occurred the radiographs showed evidences of bony atrophy. The earliest evidences of atrophy are diminished density and size of the bony shadow.

Bony thickening is a reparative process, and is sometimes seen at a later stage.

"Reduced radiability" is the name given by Lovett and Brown to a condition in which the radiographic image is blurred or obscured; not merely faint from lack of density in the bones depicted. This condition may be due to the presence of thick serum, pus, or detritus in the joint. Similar material outside of the joint will produce the same radiographic effect, and Lovett and Brown found it deceptive in a case of inguinal abscess.

Erosion or actual loss of bone substance was present in some cases, and was always shown by the radiograph. It varied from simple irregularity of the articular surface to cavities or complete absorption.

Displacements Resulting from Hip Disease.—These are grouped by Ashley[1] in three classes, and he states that a good radiograph affords the only means of positively distinguishing between these.

In group A the proximal end of the femur rests well within the acetabulum. In group B the proximal end of the femur rests near or upon the rim of the acetabulum. In group C the proximal end of the femur lies 1 inch or more from the acetabulum.

McCurdy's[2] *Transpelvic Line for Determining Displacement at the Hip.*—This line may be applied to radiographs. A line through the spines of the pubic bones passes outward across the normal position of the hip-joints and the top of the great trochanter. Displacement may be above or below this line. Lateral displacement is measured from a line drawn perpendicular to the transpelvic line and passing through the anterior superior spine of the ilium.

Fig. 683 shows the tip of the great trochanter at the level of the top of the head of the femur, and considerably above McCurdy's transpelvic line, while the head of the femur is crossed by this line. These facts would establish a fracture of the neck of the femur even if the break in the bone were not visible.

Fracture of the Acetabulum.—The examination for this injury is the same as for dislocation of the hip. The head of the femur may be nearer the median line than normally and may obscure the image of the pelvis at this point. The inner surface of the pelvis here may show protrusion or splintering.

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[1] N. Y. Med. Jour., March 10, 1906.

[2] Am. Jour. Orthop. Surgery, 1905.

Gourdon[1] published radiographs showing anatomic changes which take place after bloodless reduction of congenital dislocation at the hip.

Fracture of the Anterior Superior Spine of the Ilium by Muscular Action.—This condition was demonstrated in a case reported by Bebee.[2] Part of the pelvis may be shown in a radiograph made with the plate upon the table, and the patient lying face up, but with the pelvis turned a little toward the affected side. The tube should be over the median line of the abdomen, 2 inches above the symphysis pubis. The anticathode should be at a distance of 16 or 18 inches from the plate. A suitable exposure would be one minute, with a penetration of No. 5 Benoist and an intensity of $\frac{1}{16}$ Tousey, or thirty seconds with an intensity of $\frac{1}{4}$ Tousey. The latter requires a primary current of 18 amperes. Transformer currents greatly reduce the time of exposure.

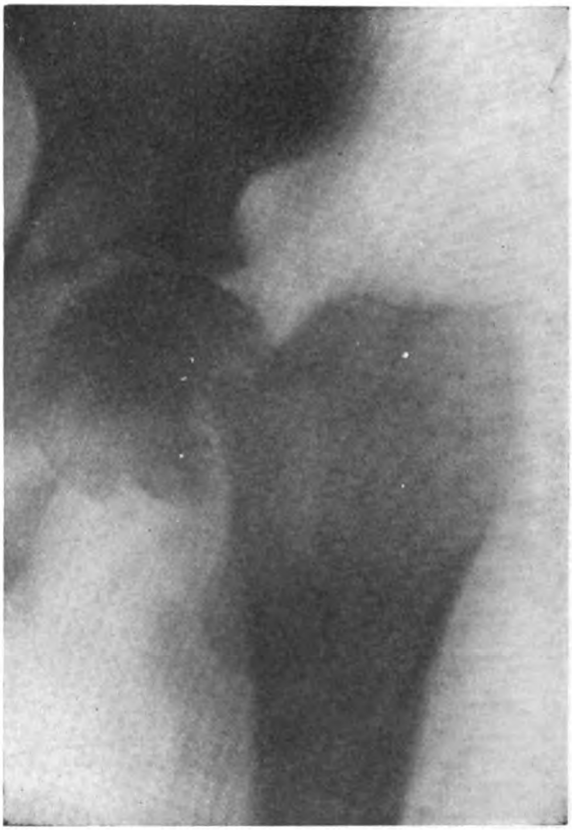

Fig. 683.—Seven months' old fracture of neck of femur with non-union. (Patient referred by Dr. R. W. Eastman.)

Congenital Dislocation of the Hip.—The *x*-ray diagnosis is based upon a radiograph, made with the patient lying upon his back with

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[1] Presse Med., Jan. 13, 1906.

[2] N. Y. Med. Journal, Nov. 17, 1908, radiograph by B. Plummer.

the plate underneath and the *x*-ray tube vertically over a point in the median line and 1 inch above the symphysis pubis. The anticathode should be at a distance of 15 inches from the plate for a small child and 17 or 18 inches for an adult.

A case had been sent to Dr. Kerley as one of infantile paralysis, but, suspecting congenital dislocation of the hip, the doctor had sent the case to the author for a radiograph. On the sound side the head of the femur, still a separate epiphysis, as the child was only three or four years old, was seen in close contact with the acetabulum, while on the affected side there was a distance of fully $\frac{3}{4}$ inch between the acetabulum and the head of the femur. The latter rested upon the ilium above the acetabulum. A glance at the fluoroscopic image did not show the dislocation, but the radiograph did so at once. The left hip was seen to be normal, with the head of the femur in contact with the acetabulum, while the head of the right hip was about 1 inch away from the acetabulum and rested upon the ala of the ilium.

Stereoscopic Radiographs of Congenital Dislocation of the Hip.—These pictures, as pointed out by Hildebrand,[1] are useful as a means of showing the direction and extent of displacement in a sagittal or anteroposterior plane. Ordinary radiography would not show this displacement, but only lateral or vertical displacement.

A Case of Old Ununited Fracture of the Neck of the Femur.—The radiograph (Fig. 683) was made seven months after injury, during which time the patient had been walking around with a crutch.

THE THIGH

Fluoroscopic examination succeeds well in determining fracture, sarcoma, exostosis or necrosis of the femur, and in locating foreign bodies. The tube for such a fluoroscopic examination should have a vacuum represented by a 3-inch resistance, No. 5 Benoist, the primary current should be about 8 amperes with rapid interruptions, and care should be taken not to expose the patient to the *x*-ray more than two or three minutes with the anticathode at a distance of 10 inches from the nearest surface. The tube may be placed further away and several brief exposures made to cover the whole operation—removal of a foreign body or dressing a fracture. For the latter purpose it is very convenient to have the *x*-ray tube under the wooden table on which the patient lies.

In making a radiograph of the thigh either a lateral or an anteroposterior view may be shown. For the latter, the patient lies on his back, with an 11×14-inch plate under the thigh, the anticathode directly over the middle of the thigh and the middle of the plate, and 15 inches from the latter. The exposure would be forty seconds with 15 amperes ($\frac{1}{16}$ Tousey) or a hundred seconds with 10 amperes ($\frac{1}{20}$ Tousey), and the vacuum should be medium, about No. 5 of the Benoist radiochromometer. Transformer currents of 25 to 50 ma. and an intensity of $\frac{1}{6}$ to 1 Tousey require an exposure of one to five seconds. An intensifying screen reducestheir exposures to one-tenth the time. A radiograph made by the author at St. Bartholomew's Clinic showed a bullet flattened out on the femur. This was removed after twelve days by means of the fluoroscope, a radiograph being taken just after the bullet had been seized by the forceps. Attempts at another hospital

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[1] Centralblatt. f. Chir., June 16, 1900, No. 24, p. 609.

to locate the bullet by probing had failed. The reason was that the bullet had glanced along the femur to a place where it was covered by dense fascia.

For a lateral view of the thigh the plate may be applied most conveniently to the inner side of the thigh, the patient lying on his side with the plate pressed between the two limbs. The author's lateral plate-holder enables the patient to lie face up with the plate held at either the outer or the inner side of the thigh.

The Author's Lateral Plate-holder in Radiography of the Thigh.—This is especially useful because it affords an opportunity to make a preliminary fluoroscopic examination with a view to placing the limb in the best position. For this purpose the patient may sit up on the operating table, with the affected limb resting on the horizontal leg-piece, while the other limb extends vertically downward, or the patient may stand beside any ordinary table, with the sound foot resting on the ground and the affected thigh resting on the table. The tube is at the side, away from the table, and the plate is held in a vertical position at the other side of the thigh. It does not matter whether this is the inside or the outside of the limb. A glance with the fluoroscope while the limb is rotated in different directions would reveal the lesion, and show the best position in which to make the radiograph. The case referred to above was one of oblique fracture of the femur without complete solution of continuity, but with a sharp projecting sliver of bone which irritated the soft tissues. There was also a fracture of the neck of the femur.

A preliminary fluoroscopic examination will also enable us to avoid the error in the diagnosis of a fracture into which a single radiograph might lead us if it chanced that the rays passed in the same plane as that in which the fragments were bent. The bone would appear perfectly straight in this position, whereas, seen from any other direction, it would show deformity. To represent the condition truly the *x*-ray should shine through the thigh at a right angle to the plane in which the two fragments lie. It is better to secure this position by adjustment under the guidance of the fluoroscope, and then to take one correct radiograph, than to depend even upon two radiographs—anteroposterior and lateral.

The upper part of the femur requires the same intensity and quality of radiance and the same length of exposure as the hip-joint, while the lower part of the thigh affords a better picture in half the time.

RADIOSCOPY OF THE KNEE

The knee may be studied with the fluoroscope, and fracture of the patella or bony changes from tubercular arthritis recognized. A lateral view is the most useful one. Still it must be remembered that it is a thick dense portion and that the illumination required is powerful, and consequently no prolonged examination should be made. The radiograph of the knee is usually taken in the lateral direction, and if the plate is at the inner side the internal condyle will show most clearly, the external condyle appearing larger and less distinct. Placing the plate at the outside will give a better picture of the external condyle. The anticathode should be at a distance of 12 to 15 inches vertically above the center of the plate, and this point should correspond to a point just posterior to the plane of the patella and just below the level of the condyles. In this way the image of the patella shows separately and so do those of the femur and tibia. The fibula shows well in a radiograph taken with the plate at the outside. The exposure should be ten seconds with 18 amperes ($\frac{1}{14}$ Tousey), forty seconds with 12 amperes ($\frac{1}{17}$ Tousey), or two minutes with 9 amperes ($\frac{1}{30}$ Tousey), or a much shorter time with powerful transformer currents, and the vacuum should be medium, about No. 5 Benoist radiometer.

Oxygen Injections into the Knee-joint for Radiography.—Distending the knee-joint with oxygen or any other gas improves the radiograph in two ways—the bony details are brought out almost as clearly as if it were a skeleton knee; the soft parts also may be differentiated to an extent impossible under ordinary conditions. Hoffa[1] has published such radiographs.

Hoffa's method is to have the oxygen gas generated in a tank of hydrogen peroxid to which tablets of potassium permanganate are added. An aseptic injection of oxygen was at first thought to be harmless and even beneficial in certain cases (Fig. 684).

Danger of Oxygen Injection into Joints.—Jacobson[2] reports a fatal case which was attributed to nervous shock. Holzknecht has had a similar experience. In Hoffa's clinic pains are taken to see that the oxygen is chemically pure, and that the injection ceases the moment the synovial cavity is full. Schwartz considers an Esmarch bandage a necessary precaution against the gas entering a vein.

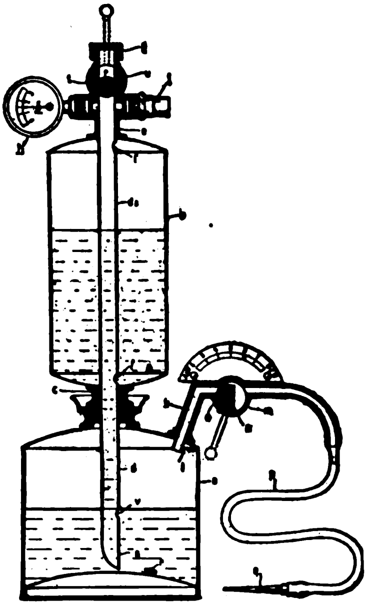

Fig. 684.—Apparatus for injecting oxygen into joints.

Radiography of the Patella.—The author's screen for soft rays comes into play in making a radiograph of the patella with the plate in front, directly in contact with the patella, and the tube close behind the knee. We secure in this way a picture of the patella as it would appear if laid bare and looked at from in front. Such a picture would be of value in cases of fracture of the patella. As explained on p. 838, the screen for soft rays enables the tube to be safely placed so near the back of the knee that the image of the portions at a greater distance from the plate is so enlarged and indistinct as to form merely a background for the clearer image of the patella. The author's contact diaphragm gives a still clearer radiograph of the patella in this position.

Fracture of the Patella.—According to Ransohoff's experiments[3] the *x*-ray reveals subperiosteal fractures of the patella which would defy diagnosis in any other way. Such a fracture, without rupture of the lateral expansion of the quadriceps tendon, is usually caused by

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[1] Berl. Klin. Woch., July 6, 1906.

[2] Arch. d'elect. med., April 10, 1907, p. 269.

[3] Jour. Am. Med. Assoc., vol. xlvii, No. 15, Oct. 13, 1906, p. 1177.

direct violence, and starts from within the bone and is widest at the articular surface. This type of fracture is one in which bony union may be expected without operative treatment.

Barlocher[1] reports the *x*-ray demonstration of bony union in the patella in cases operated upon as follows: A median incision is made and the blood clots cleaned out, the tear in the capsule is closed by sutures at each side of the patella, and a row of sutures is taken, which include the periosteum and posterior wall of the prepatellar bursa.

A Case of Bony Union After Fracture of the Patella.—The patient, a distinguished surgeon, sustained a fracture of the patella from direct violence, falling and striking his knee on the stone pavement, twelve years before a radiograph was made. The *x*-ray examination was made because of pain in the knee, but the picture revealed no abnormality except a small area of ossification in the quadriceps extensor tendon close to its attachment to the patella.

Dislocation of the Patella.—This condition of lateral displacement of the patella may be shown in a lateral radiograph made with the knee flexed or in a radiograph made with the plate in front and the tube behind. In the lateral view the patella is seen overlapping the image of the condyles instead of projecting in front of them. The anteroposterior radiograph will also show the displacement better in a position of flexion. Chevrier[2] publishes radiographs of this condition.

Radiography of Genu Valgum or Knock-knee.—The deformity is shown to consist in an inward convexity, usually of the upper end of the tibia, sometimes of the lower end of the femur, and occasionally of both. The deformity is seldom, if ever, at the knee-joint. Hoffman[3] finds the radiograph of value in determining the location of the curvature and the correct place to exert pressure by a brace. The latter should press on the abnormal curve and not on the knee.

RADIOGRAPHY OF BOW-LEGS

This shows that the deformity is due to curvature, either of the tibia or femur or both, and not to bending at the knee. Fig. 720, p. 1012, shows just where pressure by a brace should be applied. The radiograph would show where to perform an osteotomy in an older child for whom the brace would not do any good.

RADIOSCOPY OF THE LEG

The leg could be examined with the fluoroscope except for the danger, and fractures, tumors, and foreign bodies are the principal conditions studied. A convenient position is the patient standing with the foot resting upon a chair, the *x*-ray tube being at the inner side of the leg and a little behind it. This enables one to see the tibia and fibula without overlapping. The same position can be used for radiography, in which case except for the danger we would take a glance with the fluoroscope to make sure that the shadows of the two bones show separately, and then hold the plate in position at the outside and a little in front of the leg. A possible disadvantage is that the patient may not keep perfectly still. Another method consists in having the patient lie down on a table,

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[1] Correspbl. f. Schweiz. Aertze., Feb. 15, 1903.

[2] Presse Med., March 30, 1907.

[3] Annual Meeting Am. Orthoped. Assoc., August 16, 1906; Jour. Am. Med. Assoc., Sept. 8, 1906, p. 801.

with the leg resting upon the plate, and taking one picture almost directly anteroposteriorly, but with the leg rotated inward a little, and another picture almost directly from the side. In the last case either side of the leg and foot may rest upon the plate. Distance from anticathode to plate 15 inches, exposure forty seconds with 12 amperes ($\frac{1}{12}$ Tousey), or fifteen seconds with 18 amperes ($\frac{1}{14}$ Tousey), or with a transformer 25 ma. ($\frac{1}{6}$ Tousey), five seconds, vacuum medium, radiometer No. 4 Benoist.

Fig. 685.—Fracture of tibia and fibula after complete union.

The author's lateral plate-holder makes it very easy to secure the correct position, with the tibia and fibula showing separate shadows. The knee and ankle are supported on books, leaving the portion of the leg to be radiographed entirely free.

There are cases, however, in which the deformity or other lesion is not correctly shown from this direction—*i. e.*, with the ray passing through the interosseous space and the plate either in front or behind, and in which the idea of securing separate shadows of the two bones has to be abandoned. Even then, if the plate is external and the exposure rather strong, the outline of the fibula may be seen on the background of the tibia. The upper and lower parts of the fibula are easily shown in this way.

A Case of Simple Fracture of Tibia and Fibula United With Slight Malposition.—The radiograph (Fig. 685) was taken as proof of the nature of the injury in a suit against the company responsible for the accident, and not on account of any complaint against the surgeon who treated the case. A radiograph from another direction showed marked angular deformity.

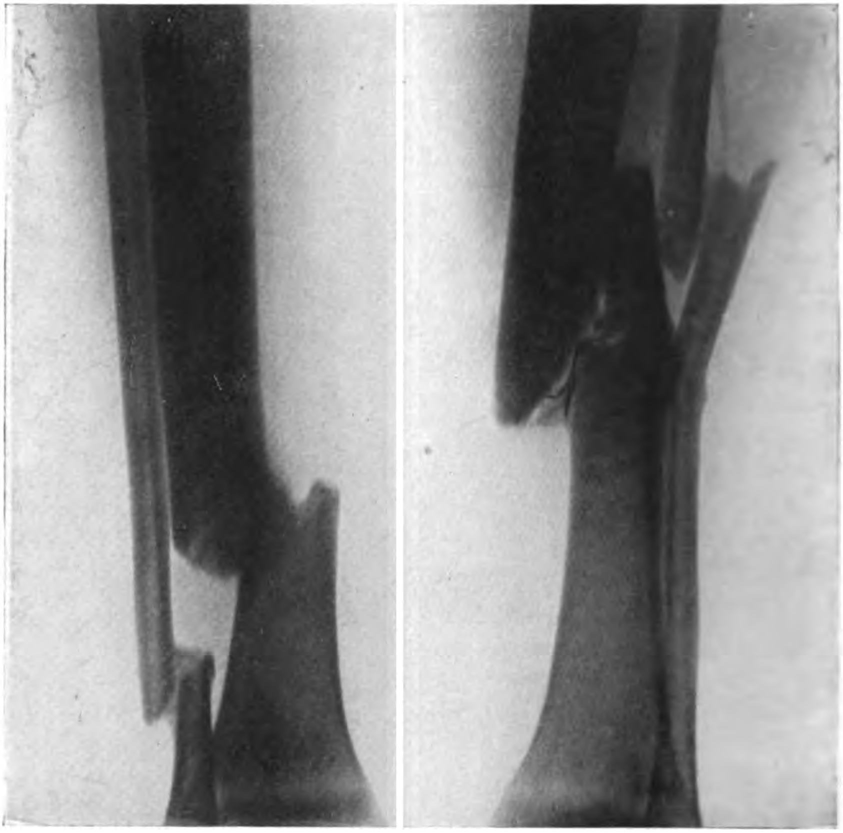

Fig. 686.—Fracture of both tibiæ and fibulæ after union with some displacement (Browne).

A Case of Simple Fracture of Tibia and Fibula After Union in Malposition.—The fracture had been a comminuted one, and the surgeon who dressed the injury had made an incision and removed fragments of bone and placed the ends in good apposition. The bones must have slipped at some subsequent dressing, for the radiograph (Fig. 686), taken six months later, shows marked lateral displacement of the fragments of both bones and some overriding and shortening. The picture shows what can be done with a high-frequency outfit.

Pott's Fracture.—This fracture of the fibula 1 or 2 inches above its lower extremity is frequently accompanied by a fracture of the internal malleolus of the tibia and sometimes by laceration of the internal lateral ligament. The deformity is produced by a bending directly to the outer side and the correct radiograph is one made in an anteroposterior direction. The tube should be in front and 1 inch above the level of the ankle-joint. The foot is fully extended, so as to avoid contact with the tube. The plate is placed behind the ankle and heel. The heel is in the way, as it means that the plate is 1 inch further from the fibula than if the plate were held close to the back of the ankle above the heel. The latter position would enable us to show a fracture a couple of inches above the malleolus, but not the lowest part of the tibia, which it is also important to show.

The author's lateral plate-holder is of great service here. The patient lies on the operating table, with the foot extended and its inner surface resting on a book. The vertical part of the lateral plate-holder (Fig. 687) holds the plate behind the foot, and the tube is placed in front and at a distance of 13 inches from the anticathode to the plate. A preliminary fluoroscopic examination is facilitated by the use of this apparatus (Fig. 688), but is extremely dangerous to the operator. The intensity being $\frac{1}{14}$ Tousey (produced, for instance, by a 12-inch induction-coil with a Wehnelt interrupter and a primary current of 18 amperes) and the penetration No. 6 Benoist, the exposure would be one minute unless the ankle were in plaster of Paris. A transformer current

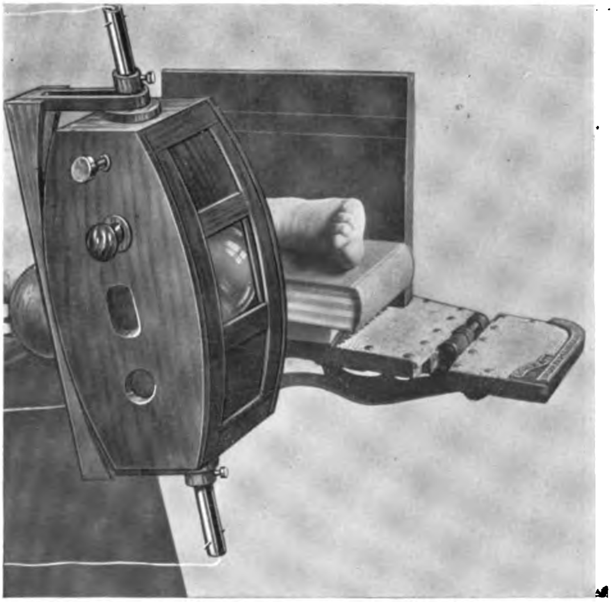

Fig. 687.—Radiography in Pott's fracture. The author's lateral plate-holder. Tube enclosed in a Ripperger shield.

Fig. 688.—Fluoroscopy of the ankle preliminary to radiography with the lateral plate-holder. An extremely dangerous practice.

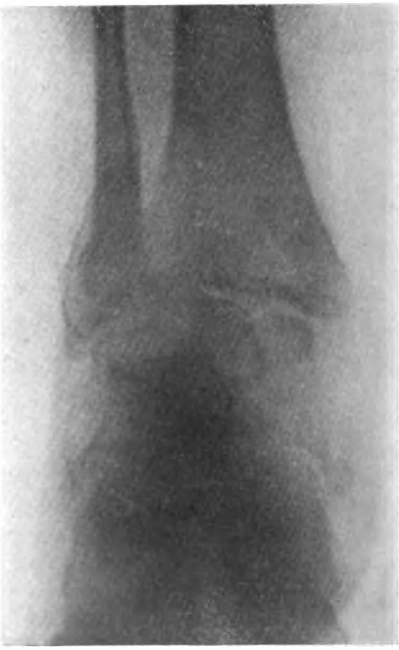

Fig. 689.—Anteroposterior radiograph of neglected Pott's fracture (Dr. H. E. Wise, St. Bartholomew's Clinic).

Fig. 690.—Lateral radiograph of neglected Pott's fracture (Dr. H. E. Wise, St. Bartholomew's Clinic).

of 60,000 volts and 25 ma., producing $\frac{1}{6}$ Tousey, would require an exposure of about five seconds.

FLUOROSCOPY AND RADIOGRAPHY OF THE FOOT

Fluoroscopy of the foot is useful principally in the diagnosis of fractures of the metatarsal bones and the phalanges, and in the location of foreign bodies. Other conditions in the foot are better studied from the radiograph. In making the latter there are several different positions. Thus, for the toes and metatarsus and anterior part of the carpus, the sole of the foot rests upon the plate with the ankle fully extended, so that the leg is drawn well back. The anticathode is vertically over the middle of the foot, at a distance of 12 inches from the plate. For the ankle-joint and the articulation between the astragalus and the os calcis the foot is turned so that the inner margin and part of the sole rest upon the plate, and a compression cylinder is used (Fig. 691). For diagnosis of flat-foot the inner side of the foot and ankle rest upon the plate, in as nearly a natural position as possible, and with the tube vertically over the prominent base of the fifth metatarsal bone.

Hallux Valgus.—Figs. 692–695 illustrate a case of hallux valgus operated upon by the author at St. Bartholomew's Clinic and reported in the New York Medical Journal. The patient, a young man of twenty-three, was almost crippled by the exaggerated deformity of both feet, the radiograph showing that the great toe was at a right angle to the corresponding metatarsal bone. The operation consisted in cutting out a wedge-shaped section of the head of the metatarsal bone. This enabled both bones to be brought into a correct line. The kodak picture shows the deformity, which looks like a swelling or bunion on the great toe-joint, but the *x*-ray at once revealed the bony deformity. As a result of the operation he is now able to be on his feet eighteen hours a day smashing baggage at the Grand Central Station.

Fig 691.—Radiography of the foot with compression cylinder.

Various Anomalies in the Tarsus.—These have been studied in anatomic specimens and in radiographs from living subjects.[1]

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[1] Wright, Jour. Am. Med. Assoc., July 28, 1906.

The *x*-ray is valuable in cases of deformity of the foot as a guide to operative treatment or to the application of the proper means of support.

A case of *talipes equinus* was radiographed with the side of the foot resting upon a plate placed horizontally on the table upon which the child lay. The tube was vertically over the opposite side of the foot. My radiograph showed that the long bones of the foot were almost in a straight line with those of the leg.

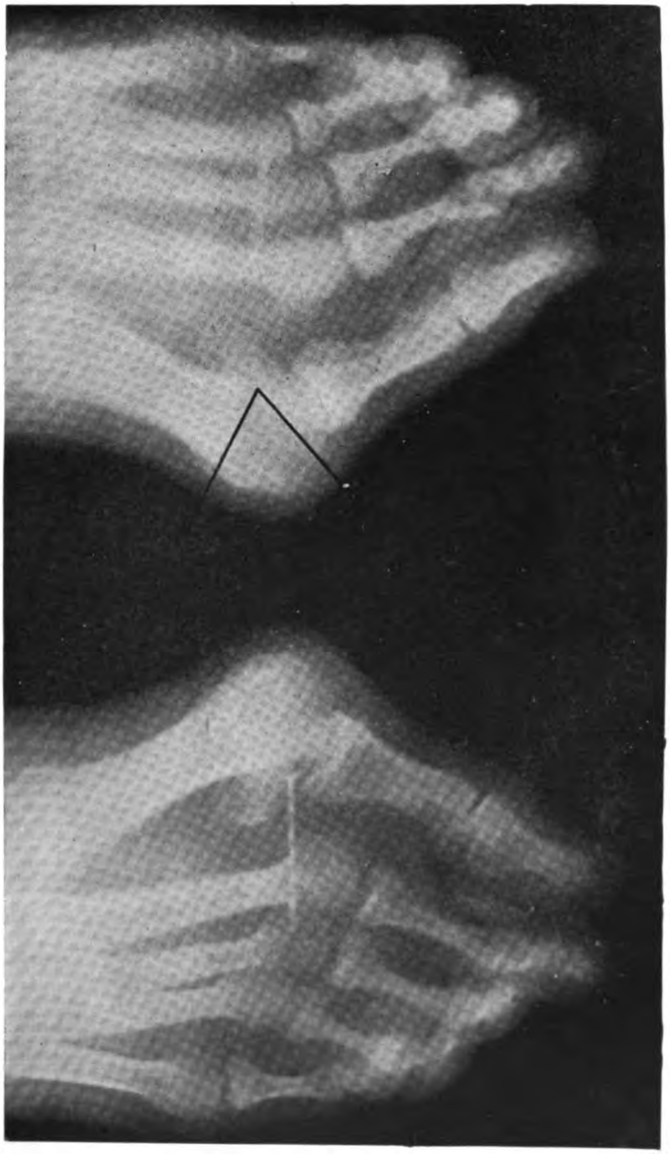

Fig. 692.—Radiograph of case of double hallux valgus before operation. The black V shows the direction of the osteotomy

Fig. 693.—Hallux valgus after operation on one foot.

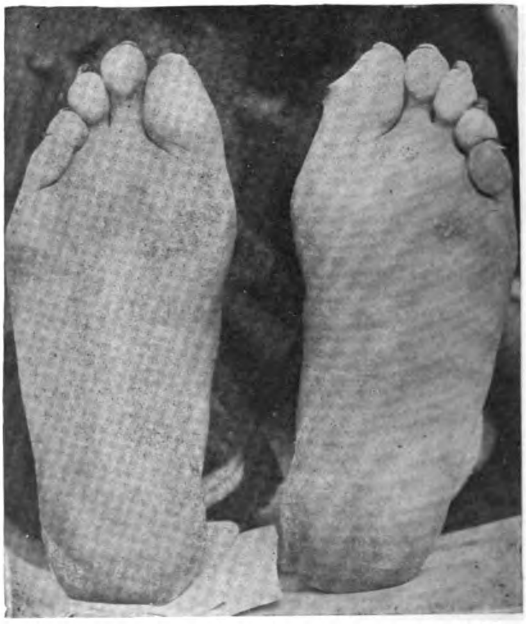

Fig. 694.—Hallux valgus after operation on both feet.

A case was examined for possible fracture of some bone in the tarsus. The foot was deformed in consequence of infantile paralysis producing *talipes equinus.* When the man was barefooted he was almost a cripple, but when he wore a specially constructed shoe he was able even to take part in athletic contests. It was at such a pastime that the injury was received which necessitated an *x*-ray examination. No fracture was found. The patient had designed a most serviceable shoe, which did not look unnatural on the outside. There was a pad inside under

Fig. 695.—Radiograph of hallux valgus after operation on both feet.

Fig. 696.—Fracture of metatarsal bones (taken with Brown's high-frequency apparatus, Salem, Mass.).

the heel and tarsus and under the outer side of the metatarsus, while the inner side of the metatarsus was allowed to come down into contact with the sole of the shoe. The radiograph showed that the inner metatarsals were strongly flexed, while the outer ones were not, and the os calcis did not nearly reach the ground.

Benoist's radiochromometer was laid upon one corner of the plate to register the degree of penetration of the x-ray. This proved to be No. 8 Benoist and seemed to be excellent.

Fracture of the Tarsal Bones.—This condition is best shown in a radiograph taken with the plate against the inner side of the foot, which is to be inverted, with the tube at the outer side. The use of the author's lateral plate-holder enables one to make a preliminary fluoroscopic examination and place the tube in such a position that the ray will shine through between the bones and show their images separately. The toes are pointed upward and the heel should rest on a book. The photographic plate is placed vertically beside the foot.

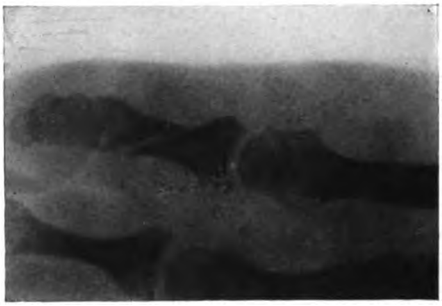

Fig. 697.—Fracture of a phalanx of the little toe.

Fracture of the Metatarsal Bones.—This injury often presents the same difficulty as a similar injury in the hand; due to the fact that the displacement is apt to be in a dorsoplantar plane, the one usually traversed by the x-ray.

Fig. 698.—Congenital absence of the terminal phalanx of the great toe.

A Case of Fracture of a Phalanx of a Toe.—The young lady, whose toe is shown in Fig. 697, caught her foot in her dress, and as she stumbled struck her foot violently against the door-post. She was in her stockinged feet and all the force was received by the little toe.

Congenital Absence of Last Phalanx of Great Toe.—Fig. 698 illustrates this condition.

THE UPPER EXTREMITY

In a small or medium-sized person a fluoroscopic examination succeeds fairly well about the shoulder. Fractures of the humerus and dislocations at the shoulder-joint show very well. Fractures of the scapula and clavicle are more difficult with the fluoroscope, and so are the different diseases of the shoulder-joint. The patient should be sitting or standing, the tube being in front and near the median line, with its anticathode at the level of the outer end of the clavicle, and about 10 inches from the nearest surface. The fluoroscope is held behind and somewhat to the side of the shoulder.

Fluoroscopy of the shaft of the humerus presents no difficulties except in very large persons, and in one of the author's cases an oblique fracture of the humerus was dressed under direct observation by the *x*-ray. In this case the contraction of the different muscles caused such an overriding of the oblique surfaces that a good result could hardly have been obtained in any other way.

Fluoroscopic examination is much less successful about the elbow-joint. The effusion which is present in cases of recent injury has the effect of making the *x*-ray image cloudy, and in any case the thickness and close relation of the bones about the elbow-joint make radiography the preferable method of examination.

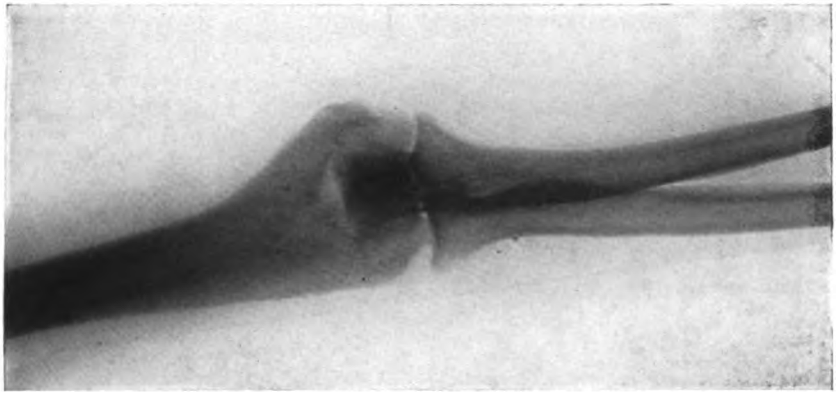

Fig. 699.—Elbow. *X*-ray tube in front and plate behind. Case of chronic rheumatism with swelling of the sheath of the ulnar nerve. Elbow appears normal in radiograph.

The forearm, wrist, and hand are simple objects for fluoroscopic examination, but even here radiography is the method for exact diagnosis. Very many times a needle may be searched for in vain with the fluoroscope and be revealed by a radiograph, having been concealed by the dense bones of the carpus. Even one of the less perfect radiographs, made directly on bromid paper and developed without any dark room, may succeed in a case in which the fluoroscope fails.

In radiographing the shoulder the patient had better lie on his back, with the plate under the affected shoulder, and the outer edge of the plate raised somewhat from the table, so as to be at a right angle to the direction of the *x*-ray. The tube is placed so that its anticathode is vertically over a point 2 inches internally to the acromioclavicular articulation and 18 inches from the plate. If both shoulders are taken for comparison it is best to take them at the same time. The tube is over the median line, at a point corresponding to the level of the acromioclavicular articulations, and a single large plate may be used, or, preferably, two 10×12-inch plates, so that each may be tipped somewhat so as to directly face the tube.

Fig. 700.—Elbow so painful that it could not be fully extended. Tube in front, plate behind. Diaphragm employed.

Such a picture shows the clavicle very well, but, of course, not so well as a radiograph taken with the plate in front of the shoulder and the tube behind, and at about the level of the acromioclavicular articulation, and 3 inches from the median line, and 18 inches from the plate. The length of exposure for a shoulder radiograph will vary with the size of the patient; it is from one hundred to a hundred and fifty seconds with 10 amperes (primary current in an induction-coil with electrolytic interrupter), or from forty to a hundred seconds with 12 amperes, or two to four minutes with 6 amperes of primary current. The vacuum should be medium, from three to six of the radiometer (Benoist), and the radiance as seen upon the fluoroscopic screen should be brilliant, the intensity may be even stronger, $\frac{1}{14}$ Tousey, and the exposure reduced to thirty seconds. A transformer with high-tension rectifier reduces the necessary exposure to a few seconds.

If an anteroposterior view of the humerus is required the patient had better lie upon his back with the arm somewhat abducted, the plate need not be larger than 8×10 inches, the point of chief interest being at the center of the plate, and the anticathode over the same point and 15 inches from the plate. Vacuum medium, radiometer No. 3 to 6 (Benoist), resistance 1½ to 3 inches, exposure sixty seconds with 10 amperes, ten seconds with 18 amperes, or twenty seconds with 15 amperes, intensity $\frac{1}{16}$ Tousey. The above figures are for a large adult (Fig. 699) and may be modified for small persons and children.

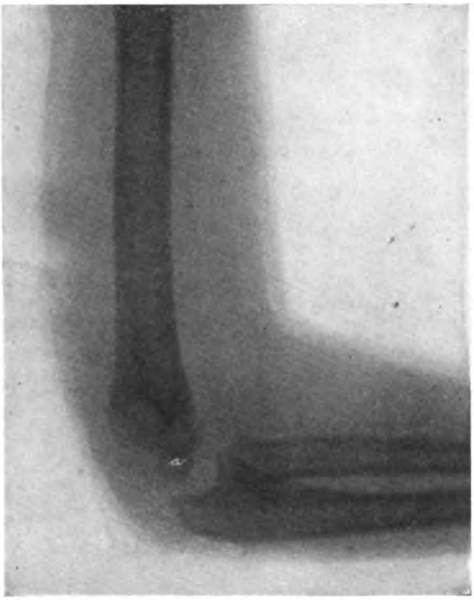

Fig. 701.—Lateral radiograph of normal elbow at age of eight years: *a*, Radial head of humerus ossified but not united. This might be mistaken for an epiphyseal diastasis (Dr. H. E. Wise, St. Bartholomew's Clinic).

To radiograph the humerus from the side it is not necessary that the patient should lie down; the plate is held between the arm and the side of the body, the tube being at the outside of the arm; otherwise the process is the same as for an anteroposterior view.

The elbow is radiographed anteroposteriorly in a position of extension, with the dorsum resting upon the plate, which is laid upon a table alongside of which the patient sits (Figs. 699 and 700), or a lateral view may be taken with the elbow semiflexed and its inner surface resting upon the plate (Fig. 701). There is one position in which the head of the radius and the other bones which take part in the elbow-joint can be shown separately (Fig. 702). The elbow and forearm should rest upon a table, before which the patient is seated. The hand is pronated and rests on the table. The elbow is partly flexed and the elbow as a whole is rotated inward as far as possible. A thin soft pad is placed over the elbow and the Albers Schönberg compression cylinder is applied to immobilize the elbow in this somewhat strained position. The *x*-ray tube is somewhat toward the outer side. In either case a 10×12-inch plate is used, and care is taken to place the anticathode directly over the space between the articular surfaces of the humerus and radius. Distance 13 inches, vacuum medium or low, 2 to 4 radiometer, exposure forty seconds with 10 amperes, or ten seconds with 15 amperes (intensity $\frac{1}{16}$ Tousey), or three minutes with 6 amperes, or five seconds with a transformer current of 60,000 volts and 25 ma. (intensity $\frac{1}{6}$ Tousey).

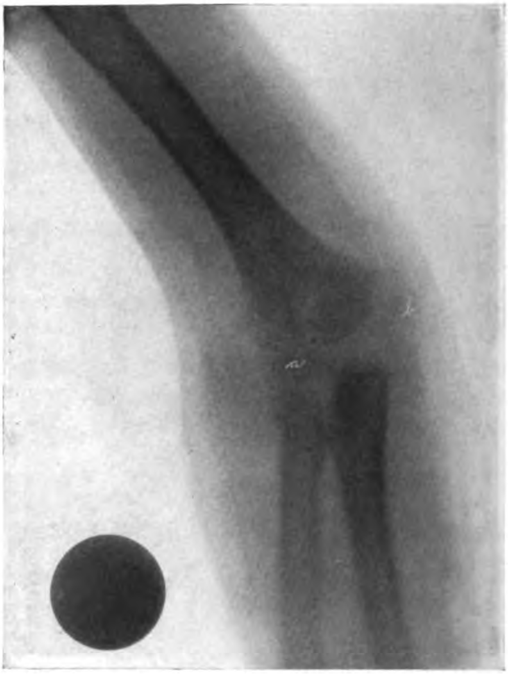

Fig. 702.—Anteroposterior radiograph of normal elbow in a child eight years old: *a*, Radial head of humerus ossified, but not united. This condition might be mistaken for an epiphyseal diastasis; *b*, internal condyle shows center of ossification not united. External condyle shows none (Dr. H. E. Wise, St. Bartholomew's Clinic).

For the forearm the patient sits at a table with the supinated forearm resting on the plate. An 8×10-inch plate will show the whole length of both radius and ulna (Fig. 703). The tube should be over the center of the plate, and the distance from the anticathode to the plate 13 inches. Exposure about two-thirds the time required for the elbow with each strength of current.

For the wrist the conditions are the same as for the forearm, the hand generally being flat upon the table in a position of pronation

(Fig. 704). Sometimes, however, the displacement of the fragments in a Colles' fracture is better shown if the radial side of the wrist is against the plate and the ulnar side away from it. This position requires that the plate shall be held vertically and the wrist supported against it. If this cannot be conveniently done, almost as good a lateral view may be obtained by laying the plate upon a table and resting the radial border of the hand and wrist upon it. The portion which is nearer the plate gives the clearer image, and this is the reason the radial side should be next to the plate in taking a lateral view of a Colles' fracture.

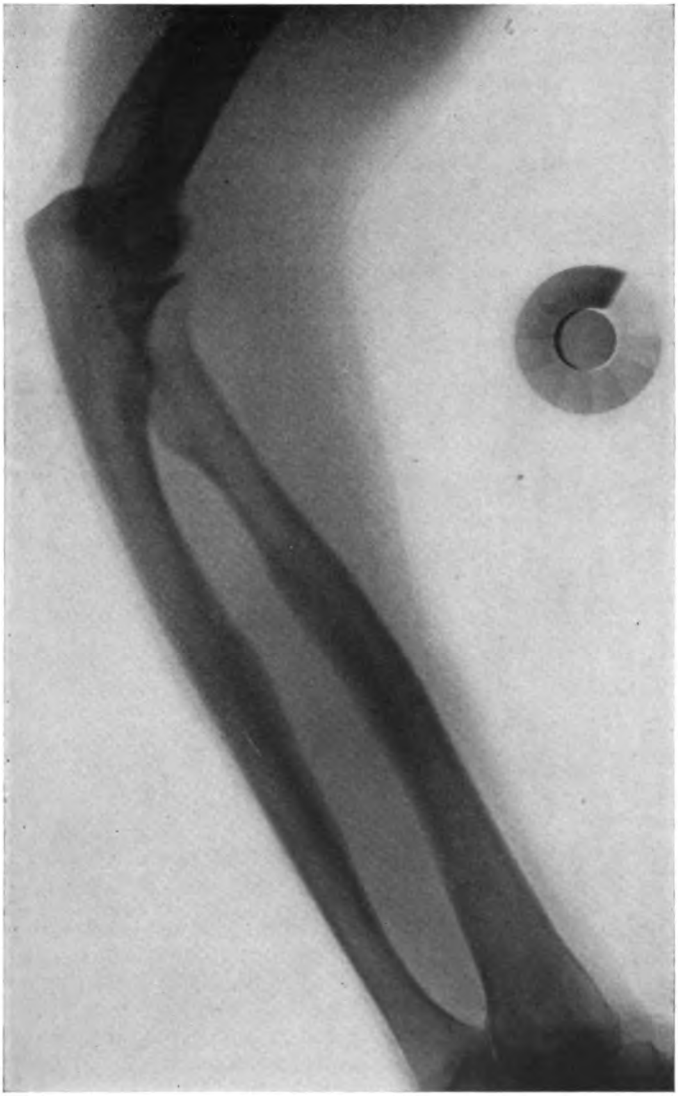

Fig. 703.—Normal elbow and forearm. Arm and forearm resting supine upon the plate.

The Best Technic for a Lateral Radiograph of the Wrist in Colles' Fracture.—The *x*-ray tube provided with the author's contact diaphragm with a 2-inch orifice is enclosed in an opaque box like the Ripperger shield. The apparatus is inverted and the ulnar border of the wrist rests upon a large piece of sole leather which covers the orifice at the distal end of the largest cylinder attached to the shield. Looking down through the wrist with the fluoroscope the hand is slightly supinated, so as to secure the dorsal profile of the radius free from that of the ulnar. A little practice will enable one to dispense with the fluoroscopy so dangerous to the operator. The plate is then laid over the wrist and rests upon two books laid alongside the wrist. The radiograph shows the condition of the radius at a glance, but must be interpreted with caution as to the apparent isolation of the pisiform bone and an apparent subluxation at the wrist-joint. Both these appearances are normal in this view of the wrist.

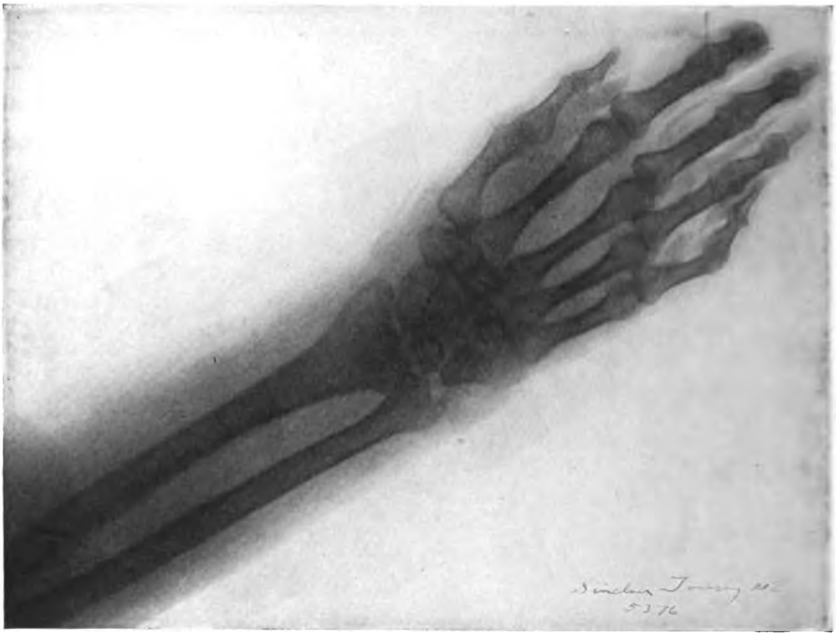

Fig. 704.—Suspected Colles' fracture. Hand prone upon the plate. Chronic rheumatism of several finger-joints.

Radiographs of the carpus, metacarpus, and phalanges are commonly taken with the palm of the hand flat upon the plate. If the whole hand is taken, the tube should be far enough away to shine between the articular surfaces of the different joints. Eleven inches from the anticathode to the plate is the minimum. At this distance the exposure would be five seconds with 18 amperes, or ten seconds with 10 amperes, or thirty seconds to a minute with 6 amperes, and the vacuum should be medium or low, resistance 1 or 2 inches, and radiometer 2 to 6. A lateral view of individual fingers is often useful in the diagnosis of fractures or dislocations and in locating foreign bodies.

A bromid-paper print, made directly with an exposure of about fifty seconds with 10 amperes and a medium vacuum, is especially useful in *x*-ray examination of the hand. It can be developed in the operating room by simply darkening the room moderately, and the whole process takes less than five minutes. The image is better than that visible with the fluoroscope, and can be studied for any length of time, thus avoiding the dangers attendant upon a prolonged fluoroscopic examination.

The Albers Schönberg Compression Cylinder in Radiography of the Upper Extremity.—As indicated in the case of radiography of the elbow, the compression cylinder is useful for immobilizing the part to be radiographed—hand, wrist, forearm, elbow, arm, or shoulder. It is useful for improving the definition in radiographs of the shoulder or elbow, but elsewhere in the upper extremity all the necessary detail may be obtained without it.

Other Convenient Methods of Immobilization of the Upper Extremity.—Sand-bags may be laid along both sides of the limb. The bags in which 5 or 10 pounds of salt are sold serve very well for this purpose. The salt itself is all right at first, but it becomes hard and inflexible after exposure to a damp atmosphere. Sand always remains soft, and adapts itself to any surface which it rests against.

A device suggested by Johnston[1] consists of a long cloth bag at each end of which is 10 pounds of shot. The bag is laid across the limb, and the heavy ends hang over the sides of the table.

The author and some other operators use a special but extremely simple bandage for immobilization. A wide bandage is split for a few inches near the middle, one end is fastened at one side of the table; the bandage is carried over the limb, completely around it, and then through the opening in the bandage where it crosses *over, not under the limb,* and thence to the opposite side of the table where it is drawn tight and fastened. This has the advantage of preventing rotation and lateral displacement of the limb, as well as preventing it from being raised from the table.

Congenital Lesions of the Upper Extremity Revealed by the *x*-Ray.—Joachimsthal[2] gives thirty-three excellent radiographs illustrating these different conditions.

Congenital dislocation of the shoulder is quite a rare condition, only one-twentieth as frequent as congenital dislocation of the hip. A case reported by Porter,[3] and also seen by Ridlon, shows that the radiographic appearance is not as striking as might be expected. The image of the affected shoulder should be compared with that of the sound shoulder made in the same position, or, in case of both shoulders being affected, the shoulder of a normal child of the same age should be radiographed for comparison.

Congenital Epiphyseal Injury at the Upper Extremity of the Humerus.—A case under the author's care illustrates the radiographic diagnosis of congenital injuries at the shoulder (Figs. 705 and 706). The patient, a boy of seven, was said to have been taken by the left arm and thrown across the room by the doctor when he was born. He was never able to move his left arm afterward. When examined there was found to be no movement at the shoulder-joint. The arm could be moved only to the extent of movement of the scapula; it could

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[1] Am. Quarterly of Roentgenology, 1907.

[2] Fort. a. d. Ged. d. Roentgen., 1900, Supplement No. 2.

[3] N. Y. Med. Journal, August 18, 1900.

not be placed vertically at the side of the head, and the hand could not be put behind the boy's back. Muscular power was good and the boy could climb a tree. The left shoulder looked as if dislocated. There was the sharp tip of the acromion process and below this a hollow. The head of the humerus, however, could not be felt either outside or inside the glenoid fossa. A radiograph was made of the two shoulders, with the tube in the median line in front and a plate

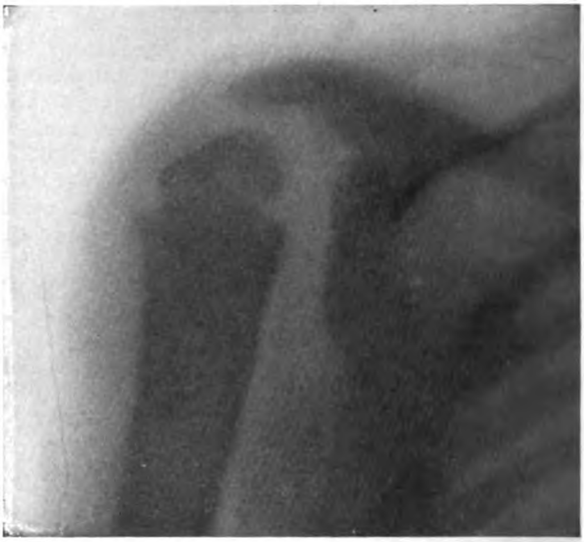

Fig. 705.—Congenital epiphyseal injury to shoulder. Patient now seven years old.

Fig. 706.—Normal shoulder. Same case as Fig. 705.

behind each shoulder. The head of the humerus on the sound side looked as large as a hen's egg; it filled the glenoid cavity and the space below the acromion process and projected beyond the latter. The shaft of the right humerus was large and well developed. The radiographic image on the left side was radically different: the head of the humerus was represented by a little knob, ½ inch in diameter, perched on top of the upper end of the shaft, which was hardly two-thirds the normal thickness. The little deformed head of the humerus was in the natural position, but did not nearly fill the space beneath the acromion process.

There was not the material for a normal shoulder-joint, and the author's advice was to leave the shoulder alone. Dr. Lorenz, of Vienna, who was shown the radiographs at St. Bartholomew's Clinic, also said, "Nothing to be done."

Supernumerary bones in any part of the upper extremity are readily studied by means of the *x*-ray. Two humeri, two ulnæ, and radii, or an abnormal number of metacarpal bones or phalanges, are found in different cases. The information thus obtained may sometimes be put to practical use in deciding on the proper surgical treatment. Such a case is reported by Markoe.[1] Fig. 707, drawn from the skiagraph, shows a supernumerary metacarpal bone placed transversely and separating the heads of the second and third metacarpals widely. The second picture shows the improved shape of the hand after removal of the supernumerary bone.

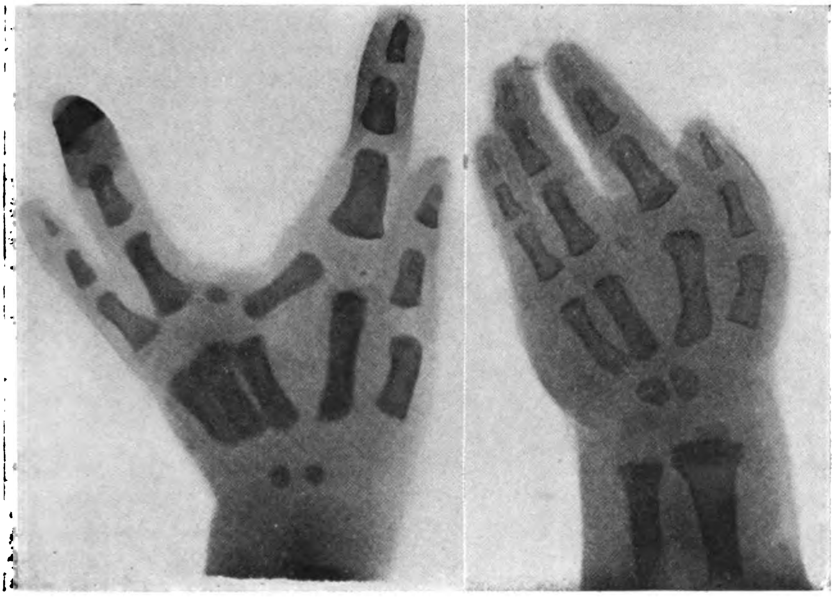

Fig. 707.—Congenital deformity of the hands.

Lund[2] shows interesting radiographic studies of cases of congenital

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[1] Bulletin Lying-in Hospital, 1906, p. 67.

[2] Med. and Surg. Reports, Boston City Hosp., 1902.

deformity of the phalanges, congenital absence of the scapula or of the radius, and similar malformations.

Mencke[1] reported a case of *reduplication of the index-finger.* The *x*-ray picture showed that the corresponding metacarpal bone presented a proximal as well as a distal epiphysis. The second metacarpal alone presented this peculiarity, and upon this he founded the classification of this as a supernumerary index-finger instead of a supernumerary thumb with three phalanges. Before the introduction of the *x*-ray 28 such cases had been reported, and they had been classified indifferently as extra thumbs with three phalanges or as extra index-fingers.

Somewhat different is the case shown in Fig. 708 (radiograph by Dr. McKenzie at the Vanderbilt Clinic). Here there were apparently *two thumbs.* One of these sprang as a sort of exostosis from the proximal phalanx of the thumb and had a single, distal phalanx of its own. This was fixed in a position of flexion.

Fig. 708.—Double thumb.

Various Anomalies in the Carpus.—These have been studied from anatomic specimens and from radiographs of living subjects.[2]

Radioscopy in Fractures of the Upper Extremity.—The treatment of fractures of the clavicle and scapula is not as much aided by the *x*-ray as that of fractures of the other bones of the upper extremity.

A *fracture of the upper extremity of the humerus* usually shows little

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[1] Archiv. f. Physiol., 1899, 245.

[2] Dwight, Jour. Am. Med. Assoc., July 28, 1906.

lateral displacement. The diagnosis is based upon the presence of a sharp line across the bone. The portion above the line is broader than the portion below and its square corners project on each side.

Fracture of the greater tuberosity of the humerus should, according to Meszytka,[1] be looked for in all doubtful cases of injury simulating subluxation of the shoulder. The radiograph should be made with the plate under the shoulder, which is slightly raised by a cushion. The arm should be adducted and rotated outward. It should be fixed in position, and the exposure should, if possible, be so short as to enable the patient to hold his breath during its continuance.

A case of supposed dislocation of the shoulder was subsequently shown by the *x*-ray to be a *fracture of the surgical neck of the humerus* with displacement outward of the upper fragment and inner displacement of the lower fragment. The case had been treated as one of dislocation; there had been union in malposition, and the case formed the basis of a law-suit against the physician, in England, who had taken care of it.[2]

Fractures of the shaft of the humerus are readily inspected by the *x*-ray and the possible overriding and bending may be avoided by applying the dressing under *x*-ray guidance.

Fractures of the lower extremity of the humerus present several different forms, and the fluoroscopic image will be found of the greatest possible assistance in getting the fragments into position. This may make the difference between a permanently impaired elbow-joint and one which is perfectly useful.

Keen[3] reports a case of operation for *non-union* after fracture of the humerus. The *x*-ray showed the presence of the aluminum-bronze wire one year after the operation, but two years later the wire had entirely disappeared.

A *fracture of the olecranon process of the ulna* will show very well in a lateral radiograph or in an anteroposterior radiograph with the plate behind. There is, in the anteroposterior picture, a perfectly normal appearance of a transverse line across the olecranon process, at the level of the superior articular surface of the radius. This must not be mistaken for a fracture. The latter produces wide separation, not a mere transverse line.

Fractures of the shaft of the radius, or ulna, or both, are seen in the fluoroscopic or radiographic image, and overlapping or lateral displacement on bending may be discovered even after the splints have been applied. One of the author's patients was a four-months'-old baby, with bones only the size of pipe-stems, and such a fat, chubby forearm that the bones could not be felt.

One of the author's radiographs showed a *"green-stick" fracture of the radius* in a child ten years of age which had not been suspected by the parents until the development of a lump due to the formation of callus at the seat of injury. The line of fracture was visible and also the callus, but there was no bending or displacement.

Natrig[4] also reports 2 cases of long-standing tenderness in the wrist which the *x*-ray showed to be due to *old ununited fractures* of different bones in the carpus.

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[1] Deut. Zeit. f. Chir., 1907.

[2] Jour. Am. Med. Assoc., Jan. 5, 1907, p. 61.

[3] Medical Chronicle, Aug., 1900.

[4] Tid. f. d. Norske Lig., 1901, p. 339.

Colles' fracture of the lower extremity of the radius is one in which some little study is required to make the *x*-ray of real service. Two radiographs are required for the diagnosis of this condition. One is made with the hand and forearm placed flat upon the plate and the tube over the back of the wrist at the seat of fracture. Fig. 704 shows the normal appearance in this position. A fracture shows a transverse line, which represents the broken surface of the lower fragment. Square corners of this project on either side, because this fragment is wider than the portion of the upper fragment which it overlaps. No lateral displacement is usually seen in a dorsopalmar radiograph.

A second picture is made in a lateral direction, which shows the line of fracture and the dorsal displacement of the lower fragment. The edge of this fragment shows especially clearly upon the back of the wrist. This lateral radiograph is made with the radial side of the wrist on the plate and the ulnar side away from it, but the wrist is turned a little so that the ray, passing from the tube in a vertical line through the radius, goes through the open air, not through the ulna or the soft parts of the wrist. The proper position is very simply obtained by having the patient crouch down at the side of the table on which the plate is laid and resting the radial border of his hand on the plate. This can be arranged in much less time than any other position, but is rather cramped, and in the case of a recent injury would be found painful. A more comfortable position for the patient is obtained by the use of the author's lateral plate-holder. The forearm and hand are supported in a natural position of semipronation, the plate is held vertically at the radial side of the wrist, and the tube is at the ulnar side. A preliminary glance with the fluoroscope will verify the correctness of the position. A lateral radiograph of the wrist shows the profile of the dorsum of the radius, but the other structures of the wrist form a confused mass from the overlapping of their shadows on the plate.

Fractures of the carpal bones are correctly radiographed with the palm of the hand resting upon the plate and the tube vertically over the back of the carpus.

An *old ununited fracture of the scaphoid bone*, which had given symptoms supposed for more than two years to indicate rheumatism, sprain, tenosynovitis, or tuberculous periostitis, was discovered by Hammond[1] by means of a radiograph. The fragments of the scaphoid bone were freed from intervening fibrous tissue and united by silver wire with a perfect result.

Fractures of the metacarpal bones are about the only ones of the upper extremity which are apt to escape detection by the fluoroscope, and they sometimes require careful study to determine by means of radiography. The difficulty is due to the fact that there is seldom any lateral displacement. The bone is bent toward the palm of the hand and this flexion does not show in a dorsopalmar view, and the line of fracture is also apt to be indistinct in this view. Twisting the hand so that the different metacarpal bones may be viewed from the side enables one to make certain of the diagnosis. A lateral radiograph of the first, second, or fifth metacarpal bone is easily obtained by placing the radial or the ulnar border of the hand in contact with the plate, while the other border of the hand is away from the plate at an angle of about 45 degrees. The *x*-ray from the tube passes obliquely over the back of

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[1] Phila. Co. Med. Soc., Nov. 23, 1904; N. Y. Med. Jour., Feb. 4, 1905.

the hand. The metacarpal bone at the border of the hand which is in contact with the plate shows very distinctly, while the other shows less clearly.

A Special Device of the Author's for Lateral Radiography of all the Metacarpal Bones.—The object is to have the plate practically in contact with all the metacarpal bones and thus to secure clear images of all of them. The hand is placed palm down on the plate and the tube is placed over the back of the hand, but so far to one side that the average angle of the rays passing through the metacarpal bones is 45 degrees. The picture (Fig. 709) is one in which the shadow of bones is wider than natural, but this can be offset by looking at the picture from an angle of 45 degrees instead of holding it perpendicular to the line of vision. It is also practicable to make a photographic copy of such a picture held at an angle of 45 degrees, and thus obtain a picture in which the bones are the natural width.

The object sought is a clear picture of the different metacarpal bones at as near an approach to a lateral view as is possible without overlapping of their images.

In the case of a fracture at the distal epiphyseal line of one of the metacarpal bones the presence of a fracture may be revealed by a dorsopalmar radiograph though the amount of bending is not shown.

Beck[1] gives a radiograph showing a lateral view of a fissured fracture of a metacarpal bone which did not show in a dorsopalmar radiograph.

Fig. 709.—Lateral radiograph of the metacarpal bones. Hand prone upon the plate; *x*-ray directed at angle of 45 degrees.

Fracture of the base of a metacarpal bone may be diagnosed by means of a dorsopalmar radiograph and sometimes by means of the fluoroscope. According to Duroux,[2] the functional result in the case of the first metacarpal is generally good because reduction can be perfectly accomplished. Fractures of the bases of the second and third metacarpals often leave the wrist in such a condition that flexion is painful, and fractures of the bases of the fourth and fifth metacarpals often result in persistent neuralgic pain. Bennett's fracture of the base of the metacarpal bone of the thumb is shown in several radiographs by Russ[3]

The *epiphyseal line* shows such a complete separation between the bony tissues of the shaft and the head of a metatarsal bone in young

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[1] N. Y. Med. Jour., May 20, 1905.

[2] Lyon Medical, Oct. 15, 1905.

[3] Jour. Am. Med. Assoc., June 16, 1906.

persons that the author has known these lines to be mistaken for multiple fractures by one unaccustomed to radiographs.

Fractures of the Phalanges.—It is so easy to obtain both a lateral and a dorsopalmar fluoroscopic view of the phalanges that there will be no difficulty in recognizing a fracture with any displacement. Simple fissures might escape detection with the ordinary box fluoroscope and be readily found with the author's magnifying fluoroscope. A single radiograph might not show a fissured fracture unless it happened to be taken in the most favorable direction. To be positive two radiographs should be taken at a right angle.

A low degree of vacuum in the *x*-ray tube is desirable for radiographing the phalanges—penetration No. 3 Benoist. There is very little tissue to be penetrated, and, of course, the lower degrees of vacuum produce radiographs with much greater contrast. Here, as elsewhere, the more intense the radiance the shorter will be the exposure and a certain degree of intensity (at least $\frac{1}{30}$ Tousey) is required to produce the best picture.

Dislocation of the Shoulder.—The examination is made with the tube in front of the shoulder and toward the median line. The plate or the fluorescent screen is placed behind the shoulder and its outer edge is further forward than the other. The head of the humerus is seen an inch or two from its normal position, where it should fill out the space extending outward from the glenoid cavity and under the acromion process.

Even in a very stout person it is possible to show this condition, though the plate is necessarily thinner and the picture fainter than in a slight person.

Dislocation of the Elbow.—A backward dislocation is shown in a radiograph made with the inner surface of the elbow resting on the plate and the tube over the outer surface. A lateral dislocation is shown in a radiograph made with the back of the elbow resting upon the plate and with the tube over the front. It may not be practicable to straighten the elbow on account of pain. In this case, the point of the elbow may rest on the plate, and the arm and forearm are at about the same angle from the plate and the tube is in the angle between them, at a distance of 12 inches from the anticathode to the plate. The radiographic shadows of the bones are almost the same as if the elbow were straight, except that while the image is quite clear near the elbow-joint the shadows of the upper part of the arm and the lower part of the forearm are enlarged and vague.

Fracture-dislocation of the elbow is shown in Fig. 710.

Subluxations of the head of the radius occur more commonly than was formerly supposed. A small child is walking beside its mother, who is holding one hand, the child stumbles, and the mother gives a quick jerk, which lifts the child to its feet and injures its arm. There is a certain amount of pain and swelling and the hand cannot be supinated voluntarily. The *x*-ray examination is not an easy one. The child is usually restless, and will not hold his arm still while the radiograph is made. The most practicable method is to have a celluloid film, 7 inches long and 4 inches wide, wrapped in light-proof envelopes and laid upon a thin wood splint or a strip of heavy cardboard. The whole is applied to the front of the limb, and kept in place by a firm bandage. The arm may then be held up before the x-ray tube, which is behind the elbow and a little to its radial side.

Fig 710.—Fracture-dislocation of the elbow.

Dislocation of the Joints in and About the Hand.—These require the same technic as fractures of the same region.

Details of the Soft Parts in a Radiograph of the Hand.—The best radiograph of the hand is taken with a low degree of vacuum, so as to have great selective absorption, and with a high degree of intensity, so as to impress every detail upon the plate, and a sufficient length of exposure so as not to require abnormally long development. The technic already described is as good a general guide as can be suggested, but experimentation with one's own apparatus will perfect the results.

The outline of the flesh shows as well as that of the bones, and every difference in the thickness of the soft tissues is brought out. Certain differences in density are revealed; the nails, for instance, show perfectly well, and faint outlines of some of the muscles and tendons are visible. As many as eight distinct shades of color may be made out on a good plate.

The arteries do not usually show. If they show distinctly it is an evidence of atheroma.

Radiographs Showing the Cutaneous Markings.—These are made by a sort of trick. Powdered bismuth subnitrate is rubbed into all the creases of the palmar surface of the hand and fingers for the picture made with the palmar surface on the plate, and into the grooves around the finger-nails and all the creases on the back of the hand and fingers for the dorsal picture. Bismuth is so opaque to the x-ray that it casts a shadow showing all the natural markings of the skin.

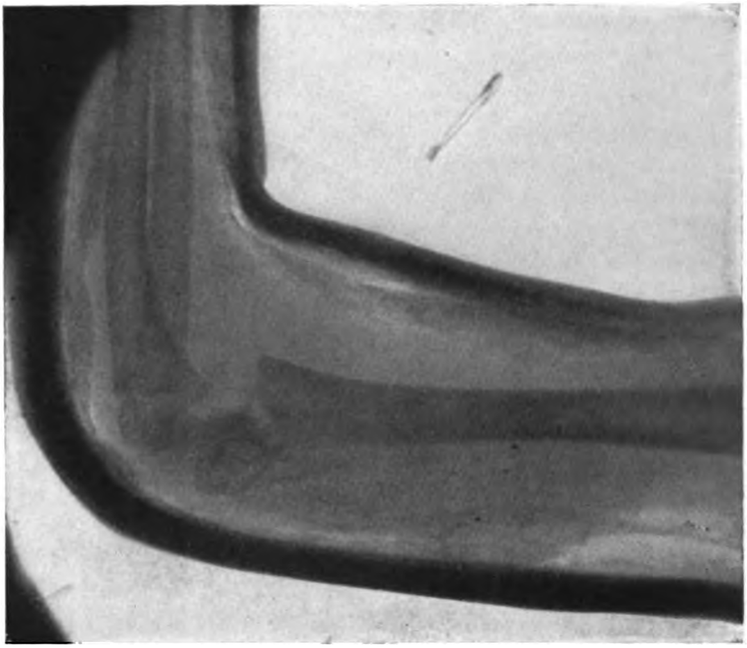

Fig. 711.—Fracture of the lower extremity of the humerus with backward displacement of the elbow. Plaster-of-Paris splints front and back.

Functionally Good Results After Fractures. Radiographic Appearances.—Torrey[1] summarizes the facts. Before the discovery of the x-ray we believed that the anatomic results were much better than the radiograph now shows them to be. The latter has established an ideal as to the result which it is often impossible to attain and which in most cases would have no advantage for the patient. The practical ideal is to secure a good functional result without deformity, recognizable by the unaided senses. The x-ray shows that very few oblique fractures of the leg or arm are treated without shortening and other deformities. One x-ray picture may exaggerate the deformity just as another may conceal it. It is unjustly exacting as to the results of fractures in legal cases.

Radiographic Appearance of Callus After Fractures.—Recent callus is not opaque to the x-ray, but permanent callus, or that which has changed into bone, is similar to natural bone in opacity.

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[1] Jour. Am. Med. Assoc., June 2, 1900.

RADIOSCOPY IN DISEASES OF THE BONES AND JOINTS

TABLE OF DISEASES OF THE BONES AND JOINTS IN WHICH *x*-RAY EXAMINATIONS ARE OF SERVICE[1]

Bones	*Periostitis.*	
	Osteitis.—Spina ventosa.	
	Osteitis Deformans.—Affects both bone and periosteum.	
	Osteomyelitis.—Abscess, necrosis, sequestra.	
	Regeneration of Bone After Operation.—Callus formation.	
	Tuberculosis.—Nearly always in epiphyses, sometimes in joints.	
	Syphilis.	
	Rickets.—Coxa vara.	
	Acromegaly.	
	Chronic Pulmonary Osteo-arthropathy.	
	New Growths.—Differentiation of bony from other tumors.	Osteoma (exostoses). Chondroma. Osteochondroma. Osteosarcoma. Chondrosarcoma. Carcinoma (rare).
Joints	*Tuberculosis.*	
	Coxitis.	
	Syphilis.	
	Arthritis Deformans.	Rheumatoid arthritis (atrophy of bone and all joint structures). Osteo-arthritis (hypertrophy of bone and cartilages). Charcot's disease.
	Rheumatism.—Acute and chronic.	
	Gout.	
	Deposits about joints, including urate of soda or lime salts.	
	Loose Cartilage.	

RADIOGRAPHY IN TUMORS OF THE BONES AND JOINTS

Radioscopy of bony tumors enables one to differentiate neoplasms from osteomyelitis and syphilis and to see whether the tumor is encapsulated or diffuse, whether it is accompanied by fracture, and whether there are metastases.

Tumors about the shoulder sometimes require an *x*-ray examination to determine whether they are of bony origin or are of the soft parts only. One of my patients had a tumor resembling a sarcoma of the shoulder, but the radiograph showed normal bony tissues. An operation was performed by the author on very different lines from what would have been required had the *x*-ray shown bony involvement. The tumor proved to be a fibroma.

Sarcoma is characterized in the radiograph by swelling and rarefaction of the bone affected, and this is apt to be of a rather general distribution in the affected part of the bone.

An interesting case was referred to the author by Dr. Gallant. There had been pain and swelling about the knee following a slight fall sustained two months previously. The radiograph showed that a practically spontaneous fracture of the femur had occurred. There was very little about the radiographic appearance to suggest more than a simple fracture, except the fact that the bone was soft enough at the place of fracture to permit of impaction. This would hardly be expected to occur in a woman twenty-four years of age with a normal femur and bending of 45 degrees as was the case here. A microscopic examination made the diagnosis certain and the thigh was amputated.

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[1] Slightly altered from Williams, "The Röntgen Ray in Medicine and Surgery."

It is sometimes more and sometimes less difficult to see just where a tumor ends in the bone than is the case with other diseases of bone.

Carcinoma when it occurs in bone presents a radiograph similar to that of sarcoma. The differential diagnosis is based upon the history and other similar considerations.

Benign cysts occur in bone, and are seen in the radiograph as large, sharply defined, rounded areas of translucency. Such a cavity was found by the author in a case of tic douloureux. It was very small and in a portion of the lower jaw from which the teeth had long since been extracted.

Fig. 712.—Sarcoma of the elbow.

Exostoses show as projections, sometimes of normal bony tissue, and sometimes of rarefied or of unnaturally dense bony tissue, depending upon the cause of the condition.

ACROMEGALY

The changes observed by C. L. Greene[1] in radiographs of a patient who had suffered for eight years from this disease were a remarkable

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[1] N. Y. Med. Jour., Oct. 21, 1905.

enlargement of the bones, both in length and thickness. This was especially marked in the great toe.

BONY CHANGES SHOWN BY RADIOGRAPHS OF CASTRATED ANIMALS

L. Richon and P. Jeandelize[1] find that rabbits, which are castrated when young, show certain bony changes when adult. Their radiographs show elongation of the long bones and increase of weight; these changes being most marked in the posterior extremities.

OSTEOMYELITIS AND NECROSIS

These may be regarded for the purpose of x-ray diagnosis as different stages of the same disease—the stage of inflammation, and the subsequent stage during which nature attempts to remove the dead bone produced.

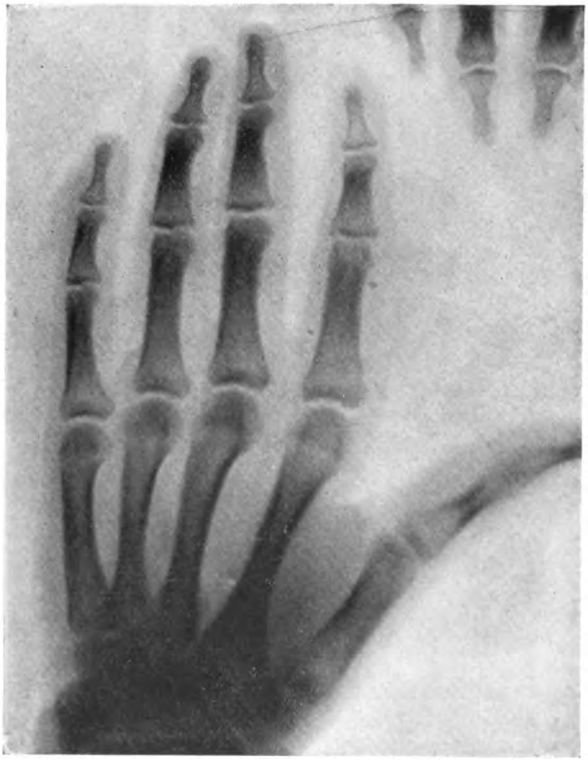

Fig. 713.—Necrosis of proximal phalanx of thumb. Showing how slightly the radiographic appearance may vary from the normal.

In cases of osteomyelitis the radiograph may show a sharply circumscribed area of unnaturally translucent bony tissue with possible swelling.

At the earliest stage in which necrosis may be said to exist there is very little difference in structure to be seen in the radiograph; only a somewhat greater translucency than normal.

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[1] Jour. de Phys. and Pathol. Generale, 1905.

The gradual formation of an involucrum, or enveloping sheath of newly-formed bone around the dead portion, may be observed in a series of radiographs. The bone eventually looks twice the natural size, and may not present the usual appearance of cancellous tissue or myeloid canal.

Fig. 714.—Absorption following necrosis of fifth metatarsal bone. (Radiograph by Dr. H. C. De V. Cornwell, St. Bartholomew's Clinic.)

Fig. 713 is of a case operated on by the author for necrosis of a large part of the proximal phalanx of the thumb. It shows how slight is the difference in appearance produced by this disease.

ACUTE OR CHRONIC PERIOSTITIS

These cases show a somewhat irregular projection beyond the outline of the bone, which is usually distinctly visible. The density of the periosteal swelling is at first only slightly greater than that of the overlying flesh, but as the case becomes chronic more and more irregular bony tissue shows in the swelling.

A CASE OF OBSCURE DISEASE OF THE SHOULDER

As a very young girl the patient had been treated by electricity for some trouble of a neuritic or paralytic type about the right shoulder, but the treatment had been discontinued because she seemed to be able to use the arm fairly well. After this she swam and played tennis, but always had to swing the body a good deal in order to assist the motions of the arm. Six years or more had elapsed when an acute attack of intense pain in the shoulder occurred. This was diagnosed as rheumatism, and the arm was kept immobilized for six or eight weeks, and a surgical examination then revealed almost complete absence of motion at the shoulder-joint. Then followed a series of most vigorous manipulations to try to break up supposed adhesions. This was very painful, and after a number of weeks produced no improvement and was abandoned. The idea of forcibly breaking up the supposed adhesions under ether was under consideration when Dr. T. M. Lloyd referred her to the author for *x*-ray examination.

At this time practically no voluntary motion could be made at the shoulder-joint, but passive movements of rotation, as well as forward or backward or to either side, were possible for 5 or 10 degrees. Voluntary movement of the arm was almost entirely accomplished by motion of the scapula, and, of course, was very limited. There was marked atrophy of the deltoid muscle and the muscles of the arm. The patient could not raise her right hand to shake hands or to carry food to her mouth. She made all such motions by lifting the right forearm with the left hand.

Fig. 715.—Case of obscure disease (tuberculosis?) of the shoulder.

An *x*-ray examination was made, which showed a perfectly normal left shoulder and (Fig. 715 made in the same position) a most unnatural condition of the right shoulder.

The disease seemed to affect chiefly the head of the humerus, which was flattened on top and had lost the natural uniform convexity of its articular surface.

It was evident that the material for a normal ball-and-socket joint was absent, and that forcible breaking up of the articulation would have produced serious injury.

Treatment by high-frequency currents applied from vacuum electrodes had a somewhat restorative effect upon the muscles but left the joint unimproved.

A long course of treatment has been conducted by Dr. Shaffer, who considers the case one of tuberculosis. A brace has been used to prevent motion at the shoulder-joint and support the weight of the arm and at the same time permit of the use of the limb. There has been great improvement in muscular power.

A corroborative fact in favor of tuberculosis is the development of a case of pulmonary tuberculosis in one of the patient's brothers.

The case is one which has puzzled some of the best surgeons and orthopedists in this country and Europe, and the varying diagnoses of rheumatism, osteomyelitis, and tuberculosis have all been regarded as verified by the appearance found in the radiograph.

It shows the importance of an *x*-ray examination at the earliest possible moment in every case of joint disease. If this case had been radiographed at different periods from its earliest manifestation the diagnosis might have been certain and much useless suffering from unavailing manipulation avoided.

SYPHILIS OF THE BONES

This disease presents itself for *x*-ray diagnosis in two general groups: 1, Syphilitic gumma; 2, syphilitic inflammation.

Gumma of Bone.—Wherever this specific neoplasm occurs the radiograph shows a combination of a destructive and a proliferating process.

Some part of the bone is usually rarefied, another part may be denser than normal, and there is often an increase in the size of the portion of bone affected.

The Periosteal Type of Gumma.—A considerable number of radiographs have been published of this variety of the disease.[1]

The typic Röntgen picture of syphilitic gumma of bone shows the shaft of the tibia, for example, presenting at one side a perfectly normal outline and the normal thickness of corticalis in the normal relation to the medullary canal, while on the other side the corticalis is thinned by irregular patches of rarefaction and its uniform outline can no longer be traced, the periosteum is intact over a swelling, which shows more or less ossification.

At the extreme margins it is quite easy to see that the swelling is a periosteal one, because there the bony contour is preserved with the less dense shadow of the periosteum gradually springing away from it.

A commencing gumma, with a slight periosteal swelling, hardly at all ossified, and with very little rarefaction of the corticalis, might not be distinguishable by the *x*-ray alone from traumatic periostitis.

The Myeloid and the Cancellous Types of Bone Gumma.—These begin on the inner surface of the corticalis of the shaft or in the cancellous tissue of the epiphysis. Neither of these present marked characteristics by which they may always be easily distinguished by the *x*-ray alone from tuberculosis, sarcoma, and other diseases.

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[1] Köhler, Fort. a. d. Geb. d. Roent., vol. x, No. 2, 75, 1906; Knochenerkrankungen im Roentgenbilde, J. F. Bergmann; Hahn, Röntgen Congress, 1906; Hahn and Deycke, Knochen-syphilis im Roentgenbilde, 1906; Ritter, Wien. klin. Woch., 1907, No. 6, p. 162; Ware, Annals of Surgery, August, 1907, p. 199.

Fig. 716.—Gumma of the soft parts not affecting the metatarsal bone. (Radiograph by Dr. B. P. Riley, St. Bartholomew's Clinic.)

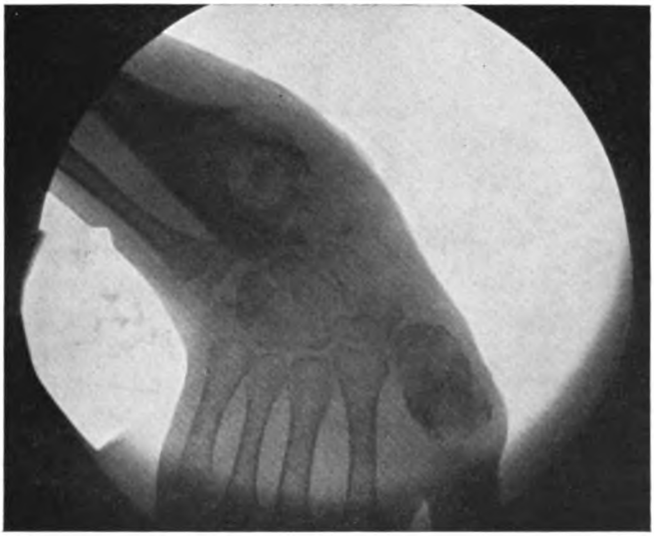

Fig. 717.—Gumma of the radius and of the first metatarsal bone. (Radiograph by Mr. Brush, Metropolitan Hospital.)

They are both myelogenous, arising in the marrow either of the myeline canal or the marrow of the spaces in the cancellous tissue of the epiphysis.

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They are apt to exist in the same bone by extension from one part to another.

Fig. 717 (Mr. Brush) shows this condition.

Spina Ventosa Syphilitica.—This disease affords a good example of a myelogenous gumma of bone. One of these fingers presents a fusiform swelling about a joint without much redness or pain and with a long, slow progress. It feels bony, but as if the bony wall was as thin as an egg-shell. The radiograph shows marked rarefaction of the epiphysis and the neighboring part of the shaft of the affected bone. The cancellous tissue of the epiphysis may be largely absorbed and the bone shrunken. There is a periosteal swelling, which presents a varying amount of ossification in different cases.

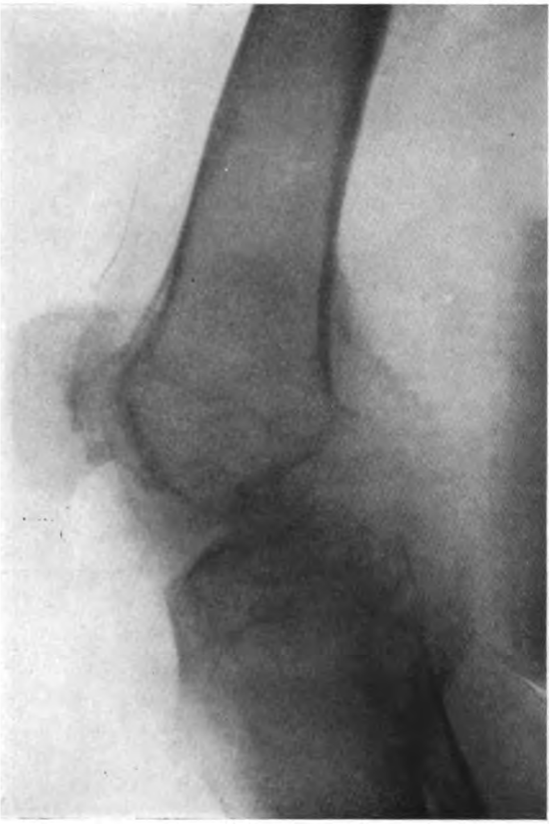

Fig. 718.—Syphilitic arthritis of the knee. (Radiograph by Mr. Brush, Metropolitan Hospital.)

The formation of new bone is about the only feature which distinguishes such a case radiographically from tuberculosis.

The author has seen cases of spina ventosa in which the radiographic appearance did not enable us to differentiate between syphilis and simple osteomyelitis. The history in one case pointed to hereditary syphilis.

A case of gumma of the epiphysis of the radius is reported by Koehler, which the radiographic appearance alone would not have enabled one to differentiate from sarcoma. His description of the radiograph is as follows: The entire bony structure of the proximal half of the radius is very much altered. The shaft is somewhat rarefied from the middle to the tuberosity and the thickness of the corticalis is reduced. The spongy tissue of the epiphysis has almost completely disappeared. The compact tissue of the epiphysis is irregular in outline and reduced to the thickness of paper and has protrusions at different places. The articular surface of the head of the radius is practically normal. The only difference between this and the radiographic appearance of a sarcoma is that, in the latter case, there is usually a sharply defined dividing line between the diseased and the sound bony tissue.

SYPHILITIC INFLAMMATION OF THE BONES (NON-GUMMATOUS)

A patient suffering from syphilis is peculiarly liable to every form of acute or chronic bony lesion which may be covered by the broad term inflammation. Some of these are quite similar to simple inflammatory processes of the same type, but very often the *x*-ray will show a decided difference.

A radiograph of a patient at St. Bartholomew's Clinic, with a somewhat tender fusiform swelling of the tibia, showed that this was a pure hyperplasia and sclerosis. The other factors in the history confirmed the impression derived from the radiograph that the process was due to hereditary syphilis.

Ware calls attention to the occurrence of syphilis in joints, especially the elbow, secondary to syphilitic osteochondritis at the epiphyseal line. The upper epiphyseal line of the radius is intra-articular.

The secondary results of gumma of bone show in a radiograph taken at a later stage. There may be exostosis, hyperostosis, or osteosclerosis, and some of these are difficult to distinguish radiographically from similar results following acute osteomyelitis or sometimes healed tuberculosis.

Riley's[1] diagnostic sign of syphilis consists in an obliteration of the medullary canal, or a lack of differentiation between the cortex and canal even in exceedingly good radiographs of the long bones. He has noted this abnormal appearance even in other bones than those in which symptoms had been present. Radiographs made at different

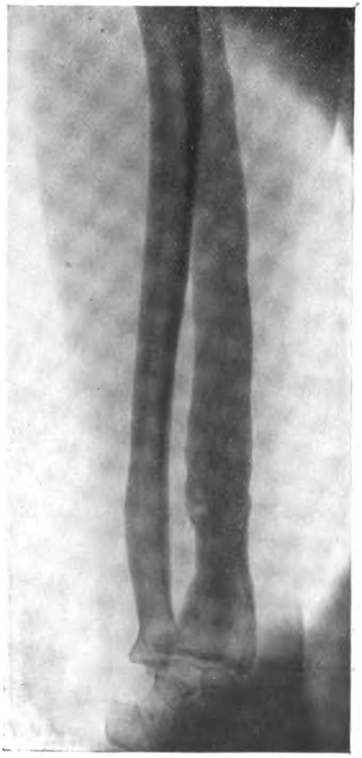

Fig. 719.—Showing Riley's diagnostic sign of syphilis; lack of differentiation between the cortex and the medullary canal of the long bones.

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[1] Dr. P. B. Riley, personal communications apropos of several cases referred to the author for radiographic examination.

Fig. 720.—Bow-legs in a case of rickets.

stages of treatment and cure show a return to normal differentiation of the medullary canal.

BONE SYPHILIS IN ANIMALS

Von Niessen has published a valuable series of radiographs (made by Koehler) illustrating the subject of syphilis of the bones in animals artificially inoculated with that disease.[1] They show the same lesions as in the case of men—exostosis of the inner side of the ribs, periostitis, ossification of the ribs, osteochondritis.

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[1] Fortschr. a. d. Geb. der Roentgen., vol. vi, p. 188, 1902.

RICKETS

The characteristic radiographic appearance in a long bone of a rachitic child is seen at the line between the bone and the cartilage. An irregular zone of ossification extends into the clear osteoid tissue. The bowed legs and other deformities which often result from the disease are shown in radiographs and the latter furnish valuable information as to the part of the bone at which an operation should be performed or brace-pressure applied (Fig. 720).

THE JOINTS IN RHEUMATISM

The radiographic appearance is described under a grouping based upon Musser's "Medical Diagnosis" (Philadelphia, 1900). It will be understood that the x-ray alone will not always enable us to differentiate between these diseases. It will almost always, however, show that the case belongs to this group of diseases, and not, for instance, to tuberculosis or malignant disease. The author makes an x-ray examination in every case of this class of disease which he treats. It is of the greatest assistance in diagnosis and prognosis. A finger-joint, showing ankylosis with continuous bony structure between the two phalanges, as in one of

Fig. 721.—Rheumatoid arthritis. Patient became a chair-invalid in spite of treatment by high-frequency currents and the x-ray.

the author's cases, is not going to be restored to functional usefulness by high-frequency currents.

Acute Articular Rheumatism.—This disease is accompanied by acute fever. It occurs in early life. There is swelling and redness of one or more large joints. This may be fugitive, leaving one joint and attacking another. It does not tend to attack the same joints on both sides of the body symmetrically.

The *x*-ray shows no change in the bones. Effusion into the knee-joint is almost always recognizable in the radiograph, the floating patella and the pouch under the quadriceps tendon being evident.

Chronic Articular Rheumatism.—This is a disease of later life; the history of heredity is very marked. It affects several of the large joints, especially the shoulder and the knee. There is spontaneous pain as well as tenderness most of the time, but with exacerbations, due in some of the author's cases to weather changes in either direction. There is no impairment of usefulness in these joints between attacks, except in some very chronic cases, where there is stiffness or even fibrous ankylosis.

It is distinguished from chronic gout by the fact that it presents no special tendency to affect the great-toe joint or to produce deformities by a deposit of sodium urate in the ears, fingers, and about the joints.

Radiographically these joints present very little change, the bones show no rarefaction, and it is only in very chronic cases that there is some irregularity in the bony outline and an unnaturally close apposition of the articular surfaces, indicating partial absorption of the cartilages.

THE JOINTS IN GOUT

This is a disease whose diagnostic features are the presence of uric acid in the blood, a deposit of sodium urate in the joints and other tissues, a marked hereditary predisposition, the fact that it is brought on especially by errors as to food and drink, and the occurrence of certain digestive and nervous disorders. The trouble very often attacks the great-toe joint.

Acute Articular Gout.—This may not in the early attacks show any change in the radiographic appearance of the joint, but later some of the changes of chronic gout may be found.

The *x*-ray examination of a joint affected by an attack of acute gout shows that the bones are normal, and enables us at once to exclude osteomyelitis, which these cases sometimes resemble.

The presence of uric acid in the blood is determined by means of a simple test applied to serum from a blister. A little acetic acid is added to the serum and a thread is placed in it. After being kept twelve or twenty-four hours at a low temperature typic uric-acid crystals will collect on the thread.

Chronic Articular Gout.—This is a disease characterized by deformity of the affected joints, deposit of sodium urate in the articular cartilages, ligaments,and bursæ, and the presence of gouty tophi in the ear and about the joints.

The radiographic appearance of the bones is not usually very much changed, except that their articular surfaces may be unusually close together, and lack some of the rounded appearance presented when they are covered by normal cartilage. Deposits of uric acid wherever they occur are clearly visible in the radiograph, forming a mass more opaque than the flesh but not so opaque as bone.

A gouty tophus consists of a spongy mass of fibrous tissue whose meshes are filled with a white pasty substance. It shows as a clearly defined though not very dense mass in a radiograph.

THE JOINTS IN RHEUMATOID ARTHRITIS OR RHEUMATIC GOUT

This is a disease which often seems to be caused by repeated pregnancies or by privation, and is of slow and intermittent but determined progress without fever. There is no special hereditary influence and no uric acid in the blood. The vast majority of the cases are subacute or chronic.

It is essentially a bilateral, symmetric disease of many small articulations, but some larger joints may also be involved. Subluxation of the finger joints or of larger joints may occur. There may be changes in the outline of the joints due to absorption or to osteophytic processes. The osteophytic growth may cause loss of mobility in the affected joints.

The hand in a typic case of rheumatoid arthritis presents a characteristic deformity. Every finger is more or less affected. The first phalanx is either flexed or extended and the last phalanx is either flexed or extended; there may be simply flexion of the first phalanx while the others are straight. The hand is pronated and the fingers turned toward the ulnar side. The ends of the phalanges may be enlarged.

Rheumatoid arthritis differs from chronic articular rheumatism in its bilateral and polyarticular character, the absence of acute attacks brought on by climatic conditions, the greater deformity produced, and the possible involvement of the articulations of the spine. Chronic rheumatism is more apt to affect the heart and to present a history of chorea.

The radiographic appearance in rheumatoid arthritis corresponds with the apparent condition of the joint. The articular ends of the bones present the normal degree of translucency to the *x*-ray, but there are irregular knob-like projections. Some of these appear more transparent, and others have about the same transparency as ordinary compact bone. In one such case the joint between the proximal and the second phalanx of the left index-finger was permanently and irretrievably ankylosed. There is continuous bony structure right through this joint. The case is one which was sent to the author for treatment, and it was important to know the condition of the different articulations.

HYPERTROPHIC ARTHRITIS OR OSTEO-ARTHRITIS

This is a slowly progressive disease occurring in later life and in both men and women, The joints are enlarged, painful, and tender. Formation of new tissue takes place at the junction between bone and articular cartilages, and this new tissue becomes calcified, forming Heberden's nodes, but these eventually break down and destroy the contour of the articular surface. A radiograph, made at this time, will show a very irregular disorganization of bone, which can easily be differentiated from the more or less symmetric destruction seen in the atrophic type of arthritis.[1]

Chronic osteo-arthritis is the name given by Lavenson[2] to a case in which radiographs by Pfahler showed that some of the joints in the fingers were obliterated by fibrous or bony union, and others in the fingers and hands by the absorption of bony tissue. There were several luxations.

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[1] Fitch, N. Y. State Journal of Medicine, vol. vii, No. 7, April, 1907, p. 141.

[2] Jour. Am. Med. Assoc., Jan. 26, 1907.

Some entire phalanges were absorbed. The process doubtless involved other portions of the body, but only the hands were radiographed.

CHARCOT'S JOINT—THE TABETIC JOINT

A typic case of this disease presents a large white swelling of a single large joint, especially the knee, without tendency to flexion, and with decided relaxation of the ligaments from wasting of the articular ends of the bones.

The cartilages are eroded, osseous deposits occur in the ligaments, and irregular exostoses occur around the joint (Fig. 722).

Dislocation of the hip may occur from wasting of the head of the femur.

Spontaneous fracture of the pelvis or of the upper part of the femur may occur (cases reported by Liebold,[1] Féré and Durand, and Wilms). Though they are rare, they should be taken into account in cases of supposed sarcoma or tuberculosis of the hip.

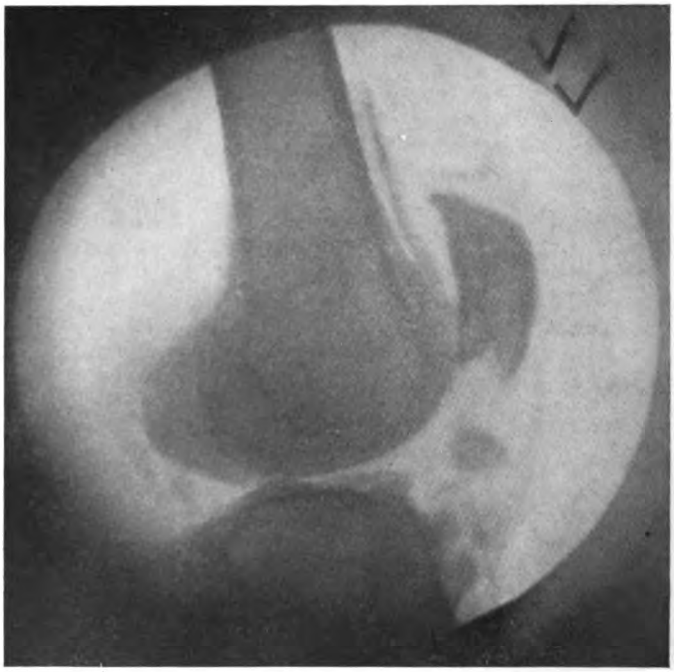

Fig. 722.—Charcot's knee-joint. (Radiograph by Mr. Brush, Metropolitan Hospital.)

The bones do not show rarefaction as in either of these other conditions, but, on the contrary, exostoses and irregular hyperplasia as opaque as ordinary bone.

GONORRHEAL ARTHRITIS

This usually involves the knee-joint, but sometimes the wrist or some other joint. There is rarely destruction of bone or any bony lesion recognizable by the *x*-ray.

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[1] Fortsch. a. d. Geb. d Roentgen., vol. x, No. 2, p. 77, 1906.

Fig. 699, p. 987, is of an elbow from which several ounces of gonorrheal pus had been evacuated a few months previously, and Fig. 723 shows a hip-joint from which several ounces of pus, also containing gonococci, were evacuated a few months after this examination.

Neither of these radiographs show any visible abnormality. Of course, if pus had been present at the time the radiographs were made the fact of fluid in the joint would have been discovered by the radiograph. Pus shows about the same density as water or as the soft tissues of the body, but a considerable collection of any kind of fluid almost always shows a distinct boundary in the radiograph.

Fig. 723.—Gonorrheal rheumatism of the hip.

Cases of destruction from gonorrheal arthritis are rare and show a radiographic appearance similar to that of tuberculosis.

Cases of ankylosis are not so uncommon. The radiograph does not show bony tissue extending across the space between the bones nor exostoses about them. The process is one of fibrous tissue formation.

TUBERCULOSIS OF BONES AND JOINTS

The principal features are *destruction* and *subluxation*.

The *x*-ray shows at first increased translucency, then some loss of detail in the bony structure, and then wasting away of the part affected. There is usually no tendency to the production of exostoses nor to the deposit of bony tissue in periosteal swellings.

The areas of rarefaction are sometimes so clearly defined as to indicate practically tubercular abscesses of bone. In other radiographs the rarefaction of the bone presents no sharply defined border separating it from the unaffected bone.

It is a very important fact that the increased translucency extends beyond the limits of actual disease. There is more or less rarefaction and atrophy of other bones beyond these limits.

Relative Diagnostic Value of the *x*-Ray and the Tuberculin Test.—W. S. Baer and H. W. Kennard discuss the diagnostic value of tuberculin in orthopedic surgery.[1] It gives an earlier diagnosis in some cases of tubercular joints than is obtainable by the radiograph alone.

The ophthalmotuberculin test is extremely simple and convenient and does not cause fever or other constitutional disturbance. A few drops in the eye are said to cause a local reaction there, if tuberculosis is present in any part of the patient. It is not mathematically certain however.

Tuberculosis of the Hip.—For this disease see p. 970.

Examples of Tuberculosis in Other Joints and Bones.—A valuable series of radiographs has been published by Exner.[2]

The *first case* was one of swelling of the carpus, three months old, and having had a fistula for two weeks. The radiograph showed tubercular changes in the proximal part of the metacarpus. There was also a noticeable translucency in the distal part of the metacarpus and in the phalanges. The compact tissue is markedly thinner than normal, and the cancellous tissue, especially in the heads of the metacarpal bones and phalanges, is very much decalcified, but the fine detail of structure was still visible.

The *second case* was of a nine-year-old child, with pain and swelling in the knee-joint for a year. During the first month of the disease the child had been able to walk, but since then it had been kept in bed by pain. There was a contracture of the knee-joint. Active motion was impossible and there was passive movement to only a limited extent. The radiograph showed tubercular changes in the joint and a much higher degree of old atrophy of the femur, tibia, and fibula. The femur, especially, showed thinning of the corticalis.

The *third case* had a fungating tuberculosis of the right carpus. The radiograph showed tuberculosis of the carpus and a high degree of atrophy of the distal ends of the metacarpal bones and phalanges and there was old atrophy of these bones.

The *fourth case* had suffered very slight pain in the hand for six months and for two months there had been a small swelling on the back of the hand. A fistula had formed and the process had extended until amputation was required. The radiograph showed tubercular changes in the carpus and the proximal parts of the metacarpus, a marked

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[1] Bulletin Johns Hopkins Hospital, 16, 13, 1904.

[2] Fortsch. a. d. Geb. d. Roentgen., vol. vi, No. 1, p. 7, 1902.

thinning of the compact tissue, and a wide-meshed appearance of the cancellous tissue at the distal part of the metacarpus and of the phalanges. Atrophy was visible in this case within two months after the beginning of the tubercular process.

The *fifth case* had a swelling of the back of the hand for six years, with a fistula for practically the whole of that time. There was very little movement at the wrist-joint. The radiograph showed tuberculosis of the carpus and metacarpus and also old atrophy of the heads of the metacarpal bones and of the phalanges.

The *sixth case,* a child six and a half years old, had suffered when two years old with a swelling of the left knee. After a long time an abscess formed which left a fistula. For the last year movement of the joint had been impossible, but the fistula had healed. The radiograph showed subluxation at the knee-joint with the changes due to a healed tuberculosis. Besides this there was old atrophy of the femur and tibia, with marked reduction in the amount of the corticalis. The atrophy of the fibula had reached a much higher degree, perhaps because the lateral displacement of the tibia had removed the weight of the body from the fibula.

The *seventh case* had suffered for two years previously from an injury to the right elbow. This was followed by pain and swelling which lasted for only a short time. Ankylosis in a position of extension gradually followed. The radiograph shows subluxation and that the joint surfaces are practically destroyed by a tubercular process. In addition, there is unnatural translucency of the humerus, radius, and ulna in the neighborhood of the joint. An operation showed that those parts were not affected by the tubercular process.

The *eighth case* had noticed for five months a swelling of the left ankle-joint with considerable pain on motion. Two months before the *x*-ray examination an incision was made over the inner malleolus from which pus exuded as a permanent fistula. The radiograph showed destruction of bone in the astragalus and the os calcis. The peripheral ends of the tibia and fibula and the healthy bones of the tarsus were strewn with translucent spots. These spots had indistinct outlines and seemed to lie in the cancellous part of the bone.

Several other cases, shown in Exner's radiographs, presented these atrophic changes in the bones of the foot from tuberculosis of the ankle; or in the bones of the hand from tuberculosis of the elbow.

EXAMPLES OF THE VALUE OF THE X-RAY IN THE STUDY OF ANATOMY

Fig. 724, a radiograph of a fish, was made with the portable high-frequency coil apparatus (Browne, Salem, Mass.).

Figs. 725–732 are radiographs showing the injected blood-vessels of normal human subjects. They were made for the author by Mr. Brush of the Metropolitan Hospital.

The Röntgen ray may be used in studying post-mortem anatomy without any limitations as to length and strength of exposure, and with the advantage derived from absolute immobility and the injection of the blood-vessels and other hollow organs with opaque substances or with transparent gases. Pictures produced in this way show the blood-vessels in their natural relations, undisturbed by dissection. They show the different hollow and solid abdominal viscera with a

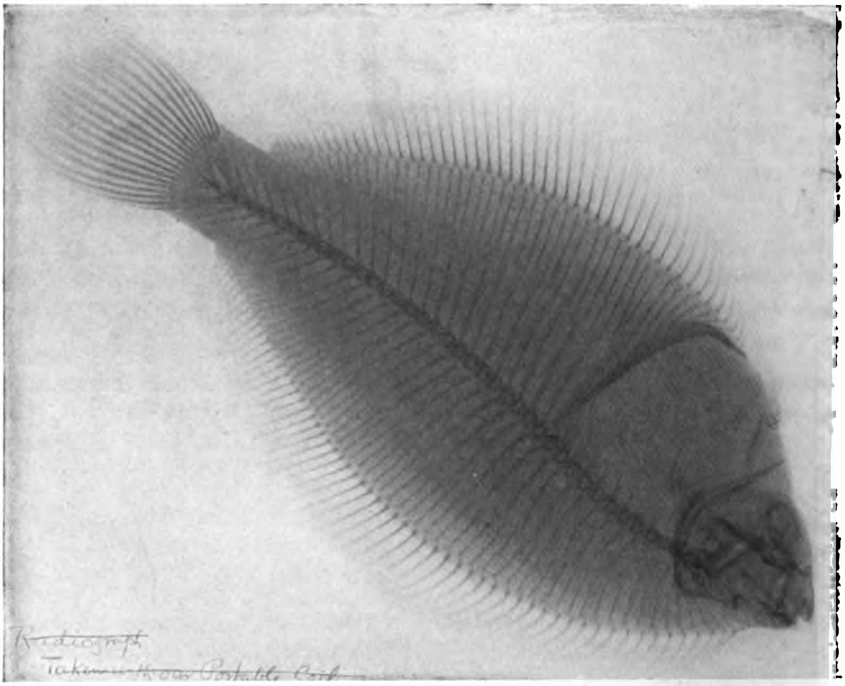

Fig. 724.—Radiograph of a fish.

Fig. 725.—Radiograph of injected arteries of the thorax.

Fig. 726.—Injected arteries of the arm.

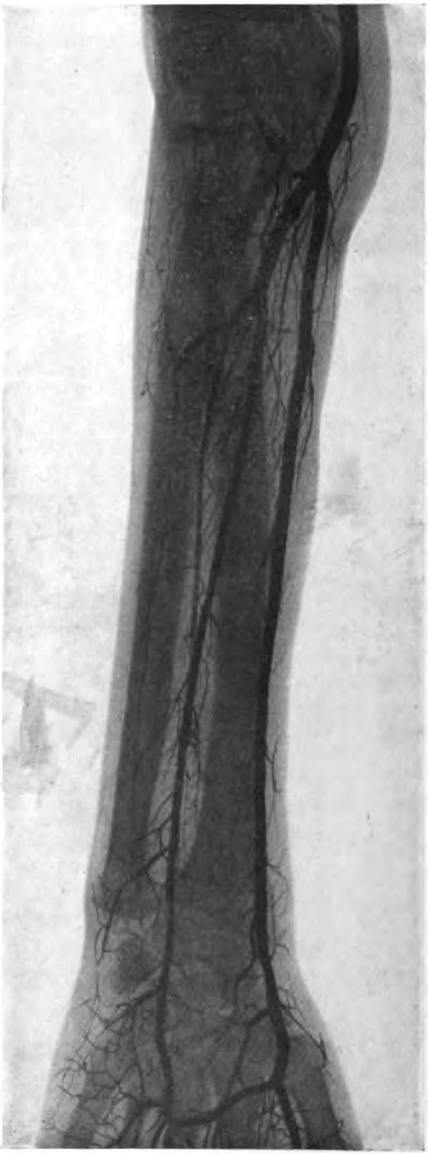

Fig 727.—Injected arteries of the forearm, including the deep palmar arch.

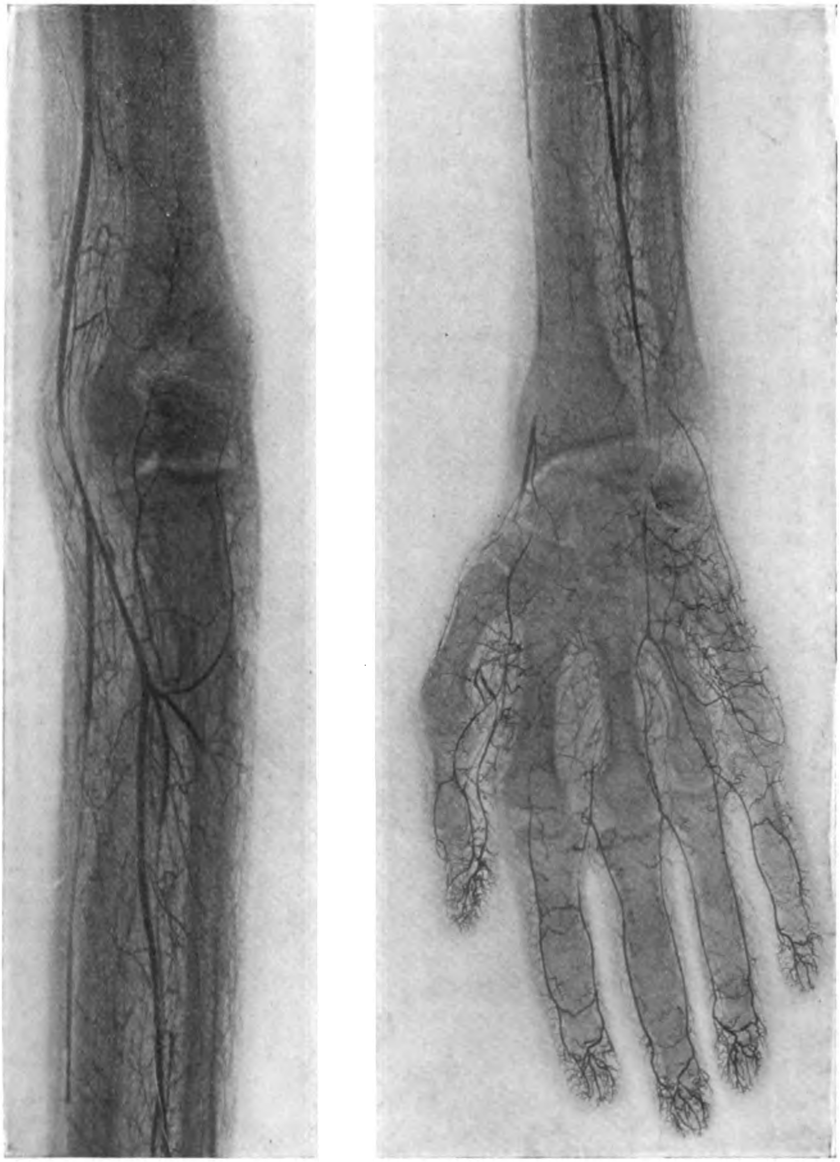

Fig. 728.—Injected arteries of the elbow and of the hand, the latter showing the distribution of the superficial palmar arch.

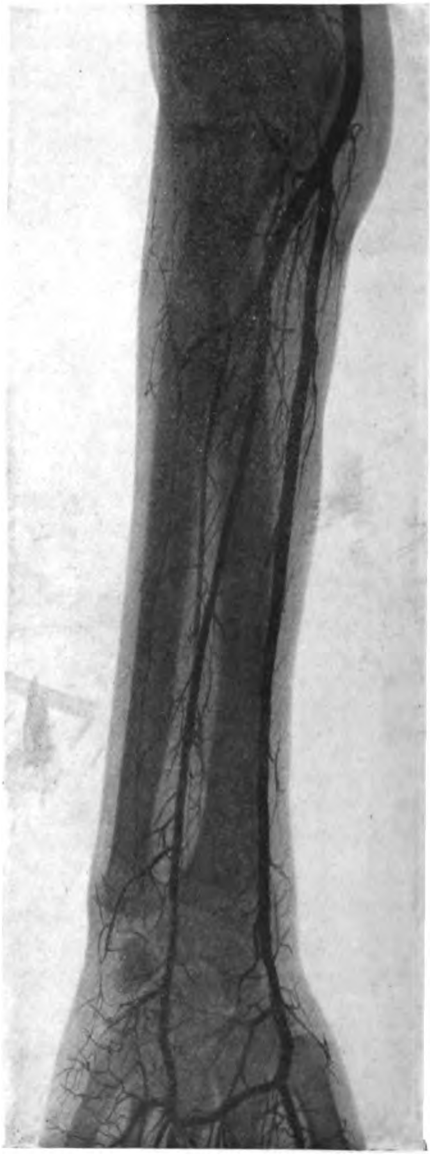

Fig 727.—Injected arteries of the forearm, including the deep palmar arch.

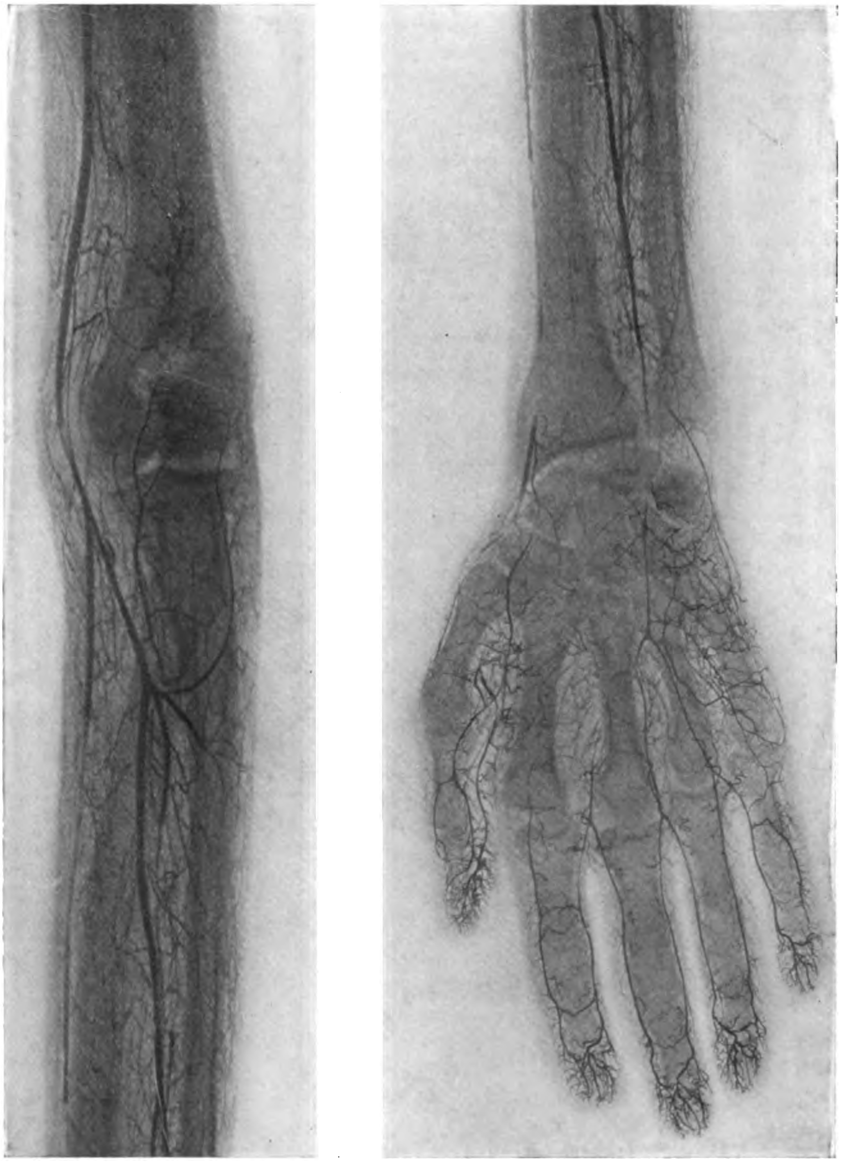

Fig. 728.—Injected arteries of the elbow and of the hand, the latter showing the distribution of the superficial palmar arch.

Fig. 729.—Injected arteries of the thigh.

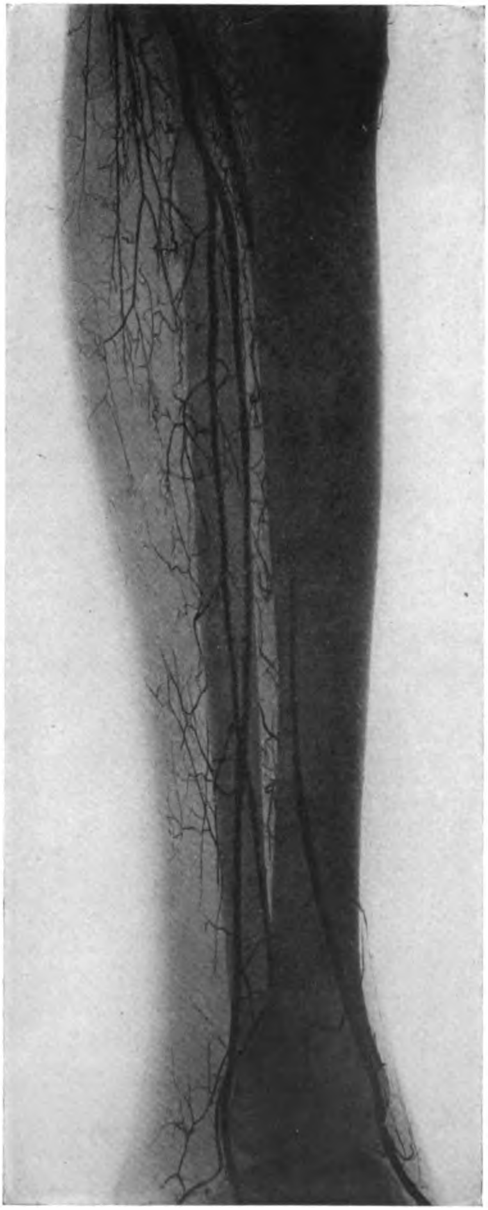

Fig. 730.—Injected arteries of the leg.

Fig. 731.—Injected arteries of the foot; dorsoplantar view.

Fig. 732.—Injected arteries of the foot; lateral view.

more clearly defined outline than is possible during life, with its respiratory, circulatory, and peristaltic movements.

The diagnostic value of these pictures lies in their use as charts for the interpretation of radiographs made from living patients. The author's radiograph of the different pneumatic sinuses of the face filled with lead shot are examples, and also Proust and Sefroit's[1] radiographic studies of the topography of the pelvic organs. The latter show especially the relations of the injected blood-vessels and the ureters.

ANATOMIC AGE DETERMINED BY RADIOLOGY

The late Dr. Rotch[2] introduced a system of determining the development of the child and its fitness for work in the school or the gymnasium or the factory, by radiographs showing the osseous development of the wrist. The following is his table of ossification as determined radiographically:

A.	First year	Os magnum, unciform.
B.	Second to third year	Os magnum, unciform, lower epiphysis of radius.
C.	Second to third year	Os magnum, unciform, radius, cuneiform.
D.	Second to third year	Os magnum, unciform, radius, cuneiform, semilunar.
E.	Third to fourth year	Os magnum, unciform, radius, cuneiform, semilunar. trapezium, or scaphoid.
F.	Fifth to sixth year	Os magnum, unciform, radius, cuneiform, semilunar, trapezium, scaphoid.
G.	Sixth year	Os magnum, unciform, radius, cuneiform, semilunar, trapezium, scaphoid, trapezoid.
H.	Sixth to seventh year	Os magnum, unciform, radius, cuneiform, semilunar, trapezium, scaphoid, lower epiphysis of ulna.
I.	Sixth to seventh year	Same as group H as to number of bones, but more advanced in development.
J.	Seventh to eighth year	Same as group I, but more advanced in development.
K.	Ninth to eleventh year	Same as group J, but the pisiform bone appears just under cuneiform, and all the carpal bones and epiphyses are much more massed and further advanced in development.
L.	Seventh to twelfth year	Same as group K, but much more advanced in development; pisiform appears plainly at lower end of cuneiform.
M.	Twelfth to fourteenth year	Very much more advanced in development than group L, and the pisiform bone almost as large as the cuneiform. All the bones of the wrist are much more developed than in any previous group.

D and E correspond to the kindergarten period, F, G, and H to the school period, and L and M to the minimum factory period. The method is sufficiently accurate to be a valuable factor in discovering evasions of the child labor laws, and in preventing overstrain at work or play in the case of children with retarded development. The literature of this subject has been tabulated by Skinner,[3] and includes articles by Long and Caldwell (1911), Roger (1908), Pryor (1905, 1906, and 1908), Rotch (1909 and 1910), and Smith (1913). The last mentioned feels that the method is of little value in the case of naval cadets, eighteen to twenty-two years of age. It should be applied at an earlier period and then may indicate future fitness for the work.

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[1] Paris Société Anatomique, March 27, 1908.

[2] The Development of the Bones in Early Life. Studied by the Röntgen Method for the Determination of an Anatomic Index. Transaction Amer. Phys. Assoc., vol. xxiv, p. 603, 1909.

[3] Interstate Medical Journal, May, 1913.

DETECTION OF PEARLS IN OYSTERS

The time-worn method has been to open the shell and kill the oyster. This results in the needless destruction of millions of pearl oysters containing no pearls and of thousands of oysters in which there are seed pearls which would increase ten-fold in value if the oysters were allowed to live another year. Experiments by the author evolved a method for radiographing 121 oysters at a time and the process has been in actual use in Ceylon.

Fig. 733.—Radiograph of Ceylon pearl oysters containing seed pearls.

The Chemic Effects of the x-Ray.—These are not striking. Starch is slowly changed into dextrin by *x*-ray exposure.

Water exposed to the *x*-ray for one hundred hours showed no separation of oxygen and hydrogen gases.[1]

PHYSIOLOGIC EFFECTS OF THE *X*-RAY

FROM MILD APPLICATIONS

A single mild exposure produces no perceptible effect, but sometimes a sensation is felt as of proximity to a source of static electricity. Taking a picture or making a fluoroscopic examination is an example of such an application.

Color-blind persons notice a perception of light when their eyes are exposed to the *x*-ray (Dorn and Uhthoff).

This fact has been found to constitute a very delicate test for the presence of *x*-rays. Albers Schönberg[2] finds that the interposition of

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[1] Kernbaum, Le Radium, 7, 1910, 275.

[2] Fortsch. a. d. Geb. d. Roentgen., vol. vii, No. 3, 1904.

sheet lead prevents this perception, but that a sheet of lead glass which will prevent action upon a photographic plate will not prevent a color-blind person from noticing a faint light sensation.

Repeated mild exposures if at short intervals, less than a week apart, produce a cumulative effect. No sensation is experienced at the time of exposure. It may produce an erythema followed by branny desquamation or regular peeling of the epidermis. This may be without pain, and if the applications are continued for a good many weeks or months will cause bronzing of the skin, amounting to the darkest tan that ever comes from exposure to sunlight. This is about the history of the surface change which it is most desirable to effect in *x*-ray treatment of deep-seated lesions. In superficial malignant disease the treatment by repeated mild applications is sometimes best, and the visible effect is as just described, with the addition of a gradual change from disease to health. One effect upon the operator from exposure to entirely too frequently repeated mild doses is to produce one of the lesions described under the head of *x*-ray dermatitis; another is to produce sterility.

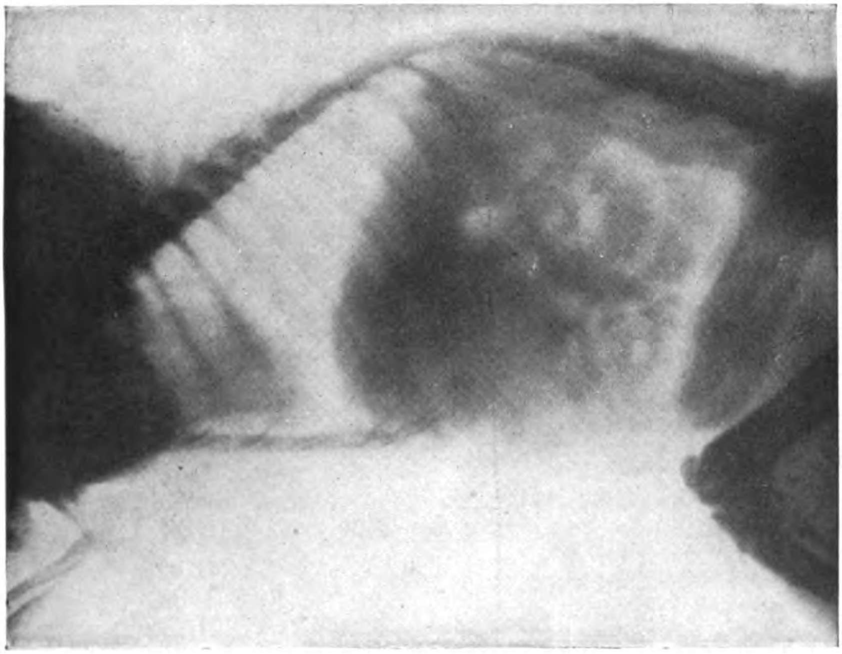

Fig. 734.—Radiograph of a pregnant cat.

There is no immediate systemic effect perceived by the patient from exposure of even the entire surface of the body to a single mild application.

Repeated exposure to mild doses has the effect of impairing the vitality of rapidly growing cells. The embryo may be killed *in utero* by a number of exposures which are without any appreciable effect upon the mother. For example, to watch the course of gestation in a cat, which had been the mother of several families of healthy kittens, the author took a number of *x*-ray pictures, beginning before any evidences of gestation were present and continuing at intervals of about a couple of weeks down to a day or so before confinement. In each case the author's own hands rested upon the cat to hold her in position upon the photographic plate, and were as much exposed to the x-ray as was the cat. The exposures were mild and short. No effect was produced upon the cat herself and none upon the operator's hands (this was a dangerous experiment), but at the natural time three mature and perfectly formed kittens were born dead. The exposures to the x-ray were stopped, and the cat proceeded to have another family of four kittens, which were born alive and healthy two and a half months after the others.

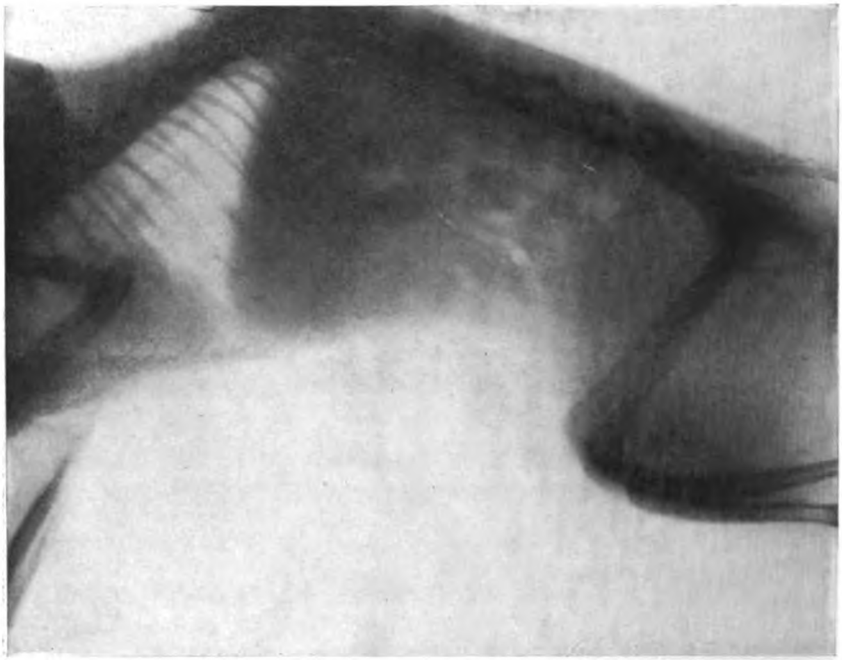

Fig. 735.—Radiograph of pregnant cat at another stage.

The details of the exposures to which this cat was subjected are given below:

Date.	Quality, Benoist.	Inches, resistance.	Amperes, primary current.	Inches, anticathode to plate.	Seconds' exposure.	12-inch induction-coil, with Caldwell interrupter, 110-volt direct current.
1904.						
Oct. 6.	5	3 or 4	10	19	10	
Oct. 12.	5	2	11	19	15	
Oct. 16.	3	3½	8	19	50	
Oct. 21.	4 or 5	8	9	15	31	
Nov. 18.	3	2+	9	16	45	
Nov. 29.	4	2½	10	15	65	First signs of pregnancy.
Dec. 17.	7	2½	9	18	60	
	No further exposure to the x-ray.					
Dec. 30.	Three mature kittens born dead.					
1905.						
March 22.	Four healthy kittens born alive.					

This is the effect to be expected, and it is regarded as undesirable to make repeated radiographic or fluoroscopic examinations of the pelvis of pregnant women. That the x-ray will not always kill the fetus, even when vigorously applied, is quite certain, and cases are recorded in which x-ray treatment for cancer of the uterus has not interfered with the progress and completion of normal gestation.[1] Probably a single x-ray examination of the pelvis would not affect the vitality of the embryo. Repeated applications of the x-ray to the pelvic organs would be very apt but not certain to do so, and would assuredly be justified in the treatment of malignant disease. In the case referred to above the child was not killed by the x-ray, but probably actually owes its life to the x-ray, which restored the mother to apparent health and enabled her to go through gestation and give birth to a healthy child.

There is no effect upon the embryo from the application of the x-ray to other parts of the patient, and in this case the pelvis should be protected from the rays either by a localizing shield about the tube or by an x-ray proof covering over the abdomen and pelvis. This covering may be a sheet of x-ray metal or of the soft x-ray proof rubber, which contains a certain percentage of bismuth, baryta, or other heavy metallic powder.

Repeated exposures to the x-ray will retard the development of newborn animals. Tribondeau and Récamier have verified this observation in the case of a kitten.[2] The development of the eyes was arrested and structural anomalies of the retina were produced. The development of the teeth and of the bones of the face was much retarded.

Action of the x-Ray Upon the Development of the Embryo of the Chicken.[3]—Fifteen Holzknecht units of x-rays prevent the development of the embryo of the chicken or arrest its development if it is already commenced; the biologic properties of the albumin are clearly modified by the x-rays; the albumin becomes less coagulable, and it is more difficultly digested by pepsin; these facts may explain the arrest of development of carcinoma treated by the x-ray.

Effect on Microörganisms.—Experiments upon the effect of the x-ray on microörganisms have been made by Russ.[4] Looking at the cultures on the lens of the microscope itself while exposed to the x-ray some microörganisms do not appear to be influenced. These are Bacillus proteus, Vibrio choleræ, and Trypanosome Lewisii. Others, like Bacillus typhi, Bacillus coli, and Bacillus pyocyaneus, show rapid and disordered movements. Even long and strong exposures to the x-ray do not interfere with the growth or virulence of different microörganisms.

Sterility from Röntgen Radiation.—Repeated mild exposures of the ovary or testis are quite generally regarded as productive of sterility. In the case of x-ray operators the loss of the power of motion in the spermatozoa, and in some cases absence of the spermatozoa, has been demonstrated a great many times by the microscope. The fact was first published by Tilden Brown and A. T. Osgood, of New York. This is not accompanied by any sexual impotence, and it is doubtless not

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[1] Laquerriere and Labelle, Bulletin Officiel de la Societe Française D'Electrotherapy et de Radiologie, Sept., 1904.

[2] C. R. de la Societé de Biologie, 58, 1031, June 6, 1905.

[3] Bordier and Galinard, Arch. d'Elect. Med. Exp. et Cliniq., 13, 491, July 10, 1905.

[4] Arch. f. Hygiene, vol. lvi, p. 341, 1906.

permanent, but a condition which disappears after the exposures have been discontinued or protection by a proper apron or shield has been adopted. This necrospermia may develop in anyone who spends much time in an x-ray room where no precautions are taken to limit the rays to some one particular direction.

The effect upon the testicle from repeated moderately severe applications of the x-ray has been studied by Bergonié and Tribondeau.[1] Six white rats were used, and entirely protected by sheet lead except where the testicles were exposed. Rat one, five applications of 2 Holzknecht units at intervals of eight days; rat two, nine applications of 1 H. at intervals of two days; rat three, eleven applications of 2 H. at intervals of two days; rat four, ten applications of 4 H. at intervals of two days. These rats had all had one testis removed before the experiment. The one exposed was removed and examined a month and a half after the last exposure. Rat five, both testes exposed five times to 4 H. at intervals of eight days, one testis removed immediately after the last séance, the other a month and a half later.

The result was the same in all. There was no change in the skin or hair, but there was a great change in the testis, consisting in the substitution of a serous liquid for the peripheral parenchyma, the same liquid separating the deep parenchymatous tubules, and a breaking down of the epididymis.

A male cat may be sterilized by x-rays filtered through 2 mm. of aluminum and with a dose of about 4 Bordier applied in one or two seances. The oviform cells survive, but disappear sooner or later.

The same authors have measured the dose required to completely and permanently sterilize a male dog,[2] and in the latter case have shown that the refractory oviform cells are incapable of regenerating epithelium.

The histologic changes are found in the seminal epithelium of the testis, which is the source of the spermatozoa, and not in the interstitial glandular tissue, whose activity is the cause of the sexual instinct and sexual activity. The secretion from the interstitial gland is an "internal" one, and is concerned with the maintenance of all the masculine characteristics of the general system.[3]

Observations on animals show that repeated mild exposure of the pelvic region results in the ovaries ceasing to produce Graafian follicles. This effect is probably temporary.

Two hundred minutes' exposure of one ovarian region of a rabbit while the other ovary was shielded produced very marked atrophy of the ovary and disappearance of the Graafian follicles. Halberstädter[4] gave this exposure in twenty days in divided doses, and found the ovary half the size of the one not exposed.

Return of Spermatogenesis After x-Ray Exposures.—The author knows of cases in which physicians working much with the x-ray without adequate protection have been found to have complete necrospermia and apparent azoöspermia, and in whom a vacation, and the subsequent use of a heavy apron of rubber loaded with baryta, and an efficient shield around the x-ray tube, have been followed by the reappearance of living spermatozoa, and the men have had children.

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[1] Archives d'Electricité Medicale, Bordeaux, France, Feb. 25, 1905.

[2] Th. Nogier and C. Regaud, C. R. de la Soc. de Biol., lxx, 5, Jan. 7, 1911, and lxx, 50, Jan. 14, 1911.

[3] Villemin, C. R. Acad. des Sciences, Paris, vol. cxlii, p. 723.

[4] Vratchebnaia Gazela, 42, 64, Jan. 16, 1905.

Laquerriere[1] reports a similar case, in which the return of spermatozoa was followed by conception.

A patient of Dr. Lapowski's[2] was a man with pruritus scroti, who was treated by the *x*-ray. Previous microscopic appearances were normal, but after two applications of ten or fifteen minutes, at a distance of 15 cm., there was necrospermia. The treatment was repeated twenty days later, and after that there was azoöspermia. Five months later, however, living spermatozoa were present.

Phillips' cases, purposely sterilized, were found to be still so six months later.

X-ray workers who have found that they were sterile have kept out of the *x*-ray room altogether, and have after a year or two had children, and then have resumed *x*-ray work and have had no more children. Others have found no living spermatozoa, in fact no discoverable spermatozoa at all, and after a couple of months' complete absence from *x*-ray exposure, followed by the use of an opaque apron and of a shield to envelope the tube, have found living spermatozoa again.

Absence of Effect on Spermatozoa Outside the Body.—Human spermatozoa, after leaving the body, are not greatly influenced by the *x*-ray. Their vitality, according to Bergonié and Tribondeau,[3] is not modified by an exposure of half an hour, at a distance of 15 cm. from the anticathode.

Precautions to be Taken.—When repeated applications of the *x*-ray are required the ovaries or testes should, therefore, always be protected from the *x*-ray.

Baldness.—Repeated mild exposures result in thinning or loss of the hair. This is only temporary, but should be guarded against.

Toxemia.—In a number of cases which have been reported, and the author is sure that many others have not yet been reported, and some have not been recognized as attributable to the *x*-ray, a single therapeutic or diagnostic application of the *x*-ray has been followed by severe constitutional disturbance. The author has seen this occur after the first mild application for cancer of the breast, and it has been noted in leukemia and other conditions in which applications are made with a view to an effect upon a constitutional disorder.

Edsall's observations[4] upon cases of leukemia, unresolved pneumonia, pernicious anemia, and gout treated by the *x*-ray show that when a single application produces an immediate marked effect, beneficial or otherwise, the examination of the urine and other means of study usually show that destructive metabolism has been, for the time being, enormously increased. Some of these patients were on a regular diet containing a measured amount of nitrogen, and the amount of nitrogen excreted had been watched for a few days before the *x*-ray was applied.

In some cases the excretion of nitrogen during the next twenty-four hours was almost doubled. These cases with increased excretion included patients with leukemia or with unresolved lobar pneumonia, and were favorably influenced by the *x*-ray applications. The increased metabolism may be due to an effect upon the tissue ferments.

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[1] Congress of the French Association for the Advancement of Science, Section on Medical Electricity, Lyons, Aug., 1906.

[2] Brown and Osgood's Article, Am. Jour. Surgery, 1905, No. 9.

[3] C. R. de la Societe de Biologie, 57, 595, Dec. 6, 1904.

[4] University of Pennsylvania Medical Bulletin, Sept., 1905; Jour. Am. Med. Assoc., Nov. 3, 1906.

The cases without an increase in nitrogenous excretion were unfavorably influenced, and some were apparently even killed by the *x*-ray application. It seems from the studies already alluded to, and also from those of Edsall and Pemberton,[1] and of Musser and Edsall,[2] that these were cases in which the large breaking down of nitrogenous tissue substances was too much of a tax for the eliminative organs, and that the latter were overwhelmed and partly incapacitated by the unusual demand upon them. The result in some cases was a toxemia caused by the excess of broken-down products in the system.

According to these authors, the application of the *x*-ray to any considerable portion of the body, especially if the hematopoietic organs, such as the spleen and the marrow of the long bones are exposed, regularly produces a tremendous increase in the destructive metamorphosis of nitrogenous tissue substances, such as nucleoprotein, and this calls for increased activity of the eliminative functions. The effect under consideration is not that of a large and toxic dose of the *x*-ray, but that of a single therapeutic or diagnostic application, which under ordinary circumstances produces no apparent symptoms. Edsall says that he knows of no drug or other therapeutic agent which produces an equal effect in ordinary dosage.

The cases in which this increased tissue destruction is liable to produce a harmful effect are those in which the patient is already in a toxemic condition, or in which there is nephritis or some similar disease which interferes with the elimination of waste products.

No constitutional effect results from such an application of the *x*-ray as is required for treating an epithelioma of the face, or for making a radiograph of the hand, if the rest of the body is shielded from the rays. But when the body is not shielded, even though one of the extremities may be nearer the *x*-ray tube, and consequently receive a stronger exposure, a constitutional effect is produced. This is also the case when the *x*-ray has to shine through a large part of the chest or abdomen for examination or treatment.

Harmful constitutional effects may be avoided, whether the patient is in a favorable condition or not, by shielding all but the portion of the patient which it is desired to examine or treat when this is a small and not a vital part; also by making sure that the patient is in a healthy condition in cases where a more general exposure or one involving the chest or abdomen is required. Such applications to a patient suffering from the toxemia of cancer, pernicious anemia, leukemia, or other similar disease, or with elimination crippled, as in cases of nephritis, should generally be avoided, but if necessary should be cautiously made.

The effect which is under consideration has not usually the cumulative character shown by the effect upon the skin and some other organs. On the contrary, a single mild general application may be followed by the most profound constitutional effect, while a number of similar applications on successive days may not produce any change in the appearance or sensations of the patient.

The **effects of a single severe application** are not perceptible at the time, but develop after one to seven days. They are chiefly upon the superficial tissues, and vary all the way from a slight erythema to a destruction of tissue right down to periosteum, which may take months

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[1] Am. Jour. Med. Sciences, February and March, 1907.

[2] University of Pennsylvania Medical Bulletin, September, 1905.

to heal or which may never do so. The lesser degree is often required in the treatment of disease and is not accompanied by visceral changes. The very greatest degree has only been produced in observations on animals—along the spine it has resulted in meningitis and death; over the abdomen even the greatest degree of overexposure has not produced gross changes in the gastro-intestinal tract. Enough has been said to show that the effect of a single very excessive exposure is so disastrous that the *x*-ray should never be applied at all by one unfamiliar with its dosage. All the elements which go to make up a knowledge of the correct dose and the way to apply it, either for diagnosis or treatment, are of the very greatest importance. Repeated severe applications have a cumulative effect if given at intervals of less than one or two or three weeks. The least severe application which will produce a visible effect upon the skin of the face is about 3 Holzknecht units (3 H.), and this may be repeated every three weeks without doing more than maintain a slight reaction. If this dose is given more frequently, or if a larger dose is given at the same interval, an increased effect is noted from each application. Another fact of importance is that a surface which has once shown a reaction to the *x*-ray is more susceptible for a long time afterward.

Experiments reported by Heinecke, of Leipzig, at the German Medical Congress of 1904, show the effect of prolonged exposure to intense radiation. His studies were especially upon the hematopoietic organs, and the animals were exposed to the *x*-ray for ten or fifteen hours at a stretch. In the marrow of the long bones there was almost a complete disappearance of the characteristic lymphocytes, only red cells being present. No gross lesions were present if the animal was killed immediately after the irradiation, but at the end of a week they were always found. In the first four hours after irradiation, in dogs, a microscopic change was noted in all the lymphatic organs, the spleen, the intestinal follicles, the lymphatic glands; this change consisted in a destruction of lymphocytes and their absorption by phagocytes. This abnormal condition had disappeared at the end of twenty-four hours. The temperature may be elevated, and the dog may lose as much as one-fourth of his entire weight in twenty-four hours. The Malpighian corpuscles of the spleen almost disappear and are replaced by connective tissue. He found that a similar effect was produced upon sarcoma, but only upon the small round-celled type.

Exposure Necessary to Produce Physiologic Effects.—The constitutional effect which is sometimes seen immediately after a treatment for cancer or leukemia, and which seems to be due to an increased metabolism, may be occasioned by an exposure of twelve seconds to the most powerful radiance in making an *x*-ray examination, or of five minutes to the milder radiance ordinarily employed in radiotherapy. The changes in the tissues of the spleen, lymphatics, and marrow, noted in the experiments on mice, rabbits, dogs, and other small animals, required very much longer exposures.

Krause and Ziegler used a 60-centimeter or 24-inch induction-coil, with a Wehnelt interrupter connected with the 110-volt direct electric lighting circuit—the primary current being 4 or 5 amperes. The distance from the animal was 20 to 40 cm. (8 to 16 in.), and the duration of exposure in mice was from two to ten hours. Mice, which were exposed four hours or longer, died in a few days as a consequence of the destructive effect upon the blood-forming elements in the spleen, the lymphatics, and the marrow of the long bones. An important fact is that the fatal effect was produced whether the exposure was a continuous one or was divided up into several exposures of fifteen or thirty minutes each. Even as short an exposure as fifteen minutes, while not producing fatal or even serious effects upon the animal, caused necrotic foci in the spleen, which could be found if the animal were killed soon after the exposure, but which were almost normal again if the animal was not killed until eleven days later.

Krause and Ziegler exposed guinea-pigs for ten hours with similar temporary effects upon the blood-forming organs, but without a fatal effect. The same ten-hour exposures produced similar results in dogs.

Sterility in men appears from Phillip's cases to be produced by an exposure of one hundred to two hundred minutes to a ray of moderate intensity, but as this was enough to produce excoriation of the scrotum, divided shorter exposures, distributed over a number of weeks, could produce this effect upon reproduction without the effect upon the skin. Occasional microscopic examinations would show when necrospermia or azoöspermia had been produced.

The exposure required to produce falling of the hair is susceptible of quite exact measurement, as explained under the head of *x*-ray dosage in the chapter on Radiotherapy. The effect is produced either by a single exposure, amounting to from 4 to 7 Holzknecht units, or by several exposures aggregating the same amount. Workers with the *x*-ray should have the *x*-ray tube enveloped in a box made of material opaque to the *x*-ray except in the direction in which the latter is to be applied, and in using the fluoroscope should have the fluorescent surface covered by lead glass. The latter protects the eyes also. A cap lined with sheet lead affords very good protection for the operator's hair. An apron made of sheet rubber containing a large percentage of baryta protects the body and genitals. Gloves containing baryta or lead oxid protect the hands.

Kienböck observed that mice which were exposed for several hours to the *x*-ray applied over the back, developed severe nervous symptoms in about three days. The eyes were closed, the spinal column flexed, and there was spastic paralysis of the limbs. The mice died. Similar exposures, though strong enough to cause the hair to fall out and to produce dermatitis, did not cause symptoms of disturbance of any internal organ in guinea-pigs and rabbits.

Of course, in the smallest animals the spinal cord is covered by such a thin delicate layer of bone and soft parts as to be very directly exposed to the rays.

In larger animals a thicker layer of soft tissues and thicker and denser bones absorb a larger part of the *x*-ray and present greater protection for the spinal cord.

Kienböck exposed a pigeon to the *x*-ray and observed falling out of the feathers, not only on the side toward the *x*-ray tube but also on the side away from the tube. The latter was apparently caused by rays which had traversed the entire thickness of the abdomen without causing a perceptible effect upon the internal organs.

The Effect of the *x*-Ray Upon the Eye.—This has been exhaustively studied by Birch-Hirschfeld.[1] He has not found any change

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[1] Arch. f. Ophthalmologie, vol. lix, p. 229.

in the retina except in cases where the exposure has been severe enough to produce clinical changes in the eye.

An exposure of 10 or 20 H., however, produces changes which may affect chiefly the anterior or the posterior structures of the eye in different cases. There is a period of incubation lasting from fifteen to forty-one days. There is a characteristic effect upon the epithelial cells of different parts of the eye. Those of the cornea become irregular and swollen and their nuclei become flattened out and sometimes divided. There are also some degenerated and vacuolized cells. The corneal epithelium may be desquamated until only a single layer remains, and may then be gradually replaced.

The eyelashes fall out.

These are the changes in the inner walls of the blood-vessels detailed in the general description of the physiologic effects of the *x*-ray.

The iris undergoes swelling and loosening of its epithelial cells and degeneration of the pigmented cells in its stroma.

The crystalline lens and its epithelial cells are unaffected. The effect upon the retina and optic nerve becomes visible at the end of several weeks. The ophthalmoscope reveals atrophy of the optic papilla. The microscope confirms this, and also shows degeneration of the ganglionic cells of the retina, with vacuolization and a characteristic change in their chromatin. This coloring-matter does not disappear as its does from the effect of the ultraviolet ray, but divides up into numerous small particles. It becomes "pulverized." There is degeneration of the optic nerve-fibers, which Birch-Hirschfeld considers secondary to the degeneration of the ganglionic cells, and not due to a direct effect of the *x*-ray on the nerve-fibers.

An eye which is exposed to the x-ray in the course of the treatment of a cancer of the eyelid gradually becomes affected, although the sight may not be destroyed for many months. The eye begins to look smaller, the conjunctiva reddens, and the cornea becomes opaque, not whitish, but because it is covered by newly formed connective tissue. This tissue contains blood-vessels and round cells and is covered by several layers of epithelium of a character similar to that of the skin.

The *iris* is infiltrated by leukocytes; most of the pigmented cells disappear; the walls of its blood-vessels undergo the usual effect from the *x*-ray.

The *retina* shows the usual *x*-ray degeneration of the ganglionic cells and of the intima of the blood-vessels. No change is to be discovered in the optic nerve-fibers. There is a very marked change in and near the macula lutea. Cysts develop which thrust aside the internal granular layer. There are spaces of almost normal retina between these circumscribed cysts.

The eye is permanently destroyed.

This effect may be guarded against by using some kind of shield protecting the whole orbit, or, if the eyelids are to be treated, the eyeball may be protected by an opaque shell slipped over the eyeball and under the eyelids. The model, shown in Fig. 736, is made of metal and has a projection on its external surface by which it may be handled when inserting and removing it. A special pair of forceps facilitates this.

Birch-Hirschfeld recommends that the use of the *x*-ray in treatment about the eye be limited to malignant and tubercular disease of the eyelids, and that not more than 8 or 10 H. should be applied once in two weeks.

These conclusions should probably be modified. The dosage seems unnecessarily and, therefore, undesirably large, and the *x*-ray has been used safely and with excellent results in trachoma.

Effect of the *x*-Ray Upon the Liver.—Experiments by Hudellet[1] show that in the adult rabbit it causes only some interference with intercellular nutrition in the liver. In a young rabbit it causes a certain degree of atrophy without necrosis. The liver of a newborn kitten undergoes changes amounting to destruction of the part of the liver directly exposed to the rays. Each exposure was usually the same except as to duration. A D'Arsonval-Gaiffe transformer was used with 1 ma. of secondary current and No. 7 Benoist rays, the distance from the anticathode to the skin being 15 mm. The exposures in two adult rabbits were one hour and two hours respectively. The young rabbits were exposed over the region of the liver for about ten minutes every day for twenty days. A newborn kitten received exposures of ten minutes every other day from the third to the twenty-first day after birth.

Fig. 736.—Protection of the eyeball in *x*-ray treatment of the eyelids.

Effect Upon the Nervous System.—Scorbo, of Naples, has noted a neuromuscular trophic action of the *x*-ray.

Several authors, including Schär,[2] have reported the occurrence of nervous disturbances after exposure to the *x*-ray, but the great majority of *x*-ray workers have never observed anything of the kind in their patients or themselves.

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[1] Arch. d'Electricité Medicale, Jan. 10, 1907.

[2] Fragebogen, April, 1906.

The case reported by Colombo[1] of severe nervous crises following therapeutic applications of the *x*-ray to the leg may possibly, in the light of Edsall's observations, be attributed to a toxemia instead of to a direct effect upon the nervous system.

Intense radiation of the brain in some of Rodet and Bertin's[2] experiments caused paralysis and convulsions and the postmortem appearance of meningomyelitis.

Tarkhanoff[3] also reported a diminution of reflexes in a frog in which the brain was irradiated.

Later observations, especially those of Krause and Ziegler,[4] seem to show that when the whole animal is exposed no effect is produced upon the brain or spinal cord, and the same may be the case when only the nervous centers are exposed.

The Effect on the Intestines.—The follicles of the intestinal wall are among the tissues which are especially susceptible to the influence of the *x*-ray. After ten hours' irradiation of the entire animal in Krause and Ziegler's experiments (*l. c.*) intestinal follicles were found immediately afterward to show necrotic foci, but these had disappeared if the animal was not killed until four days later, and a clear area, consisting partly of epithelioid cells, was found at the center of each follicle. The effect on the intestines is really part of the effect on lymphatic tissue, which occurs wherever this is to be found.

The effect on the skin is a breaking down of the hair follicles, edema, and disintegration of the epidermic cells, hyperkeratosis, and necrotic disintegration of the epithelium, inflammatory exudation into the corium, and thickening of the intima of the large vessels in the skin. *Krause and Ziegler found no changes in the liver, pancreas, the mucous or salivary glands, the thyroid gland, or the kidneys.*

Effects Upon the Kidney.—As has just been stated, the latest and most complete series of experiments leads to the conclusion that the kidneys undergo no change referable to the direct action of the *x*-ray. Cases of nephritis, sometimes occurring in experiments, were considered as due to the anesthetic. (Dogs, especially, had to be kept quiet in this way long enough for the exposure, which, however, is entirely without sensation.)

Edsall's observations make it seem probable that cases of nephritis after *x*-ray exposure are due to the increased metabolism occasioned by the exposure.

A recent report of a case of nephritis cured by applications of the *x*-ray to the kidney is not at all negatived by our knowledge of the effect of the *x*-ray upon that organ.

Warthin's observations upon the effect of the *x*-ray upon the kidney show that the direct effect is very slight, even when animals are exposed to very long applications. The indirect effect is proportional to the destruction of leukocytes and the exaggeration of uric acid excretion, and is most marked in leukemia. In some cases of the latter disease after *x*-ray treatments he has found the kidneys sclerotic, and with calcareous deposits and fatty degeneration of certain tubules, while others showed pressure necrosis.

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[1] Transac. Am. Roentgen Ray Society, 1906.

[2] Medical News, p. 111, 1897.

[3] Abstracted in Wien. Med. Woch., No. 12, 1897.

[4] Fortsch. a. d. Gebiete d. Roentgen. Strählen.

Effect Upon the Blood.—There is a direct effect upon the white blood-cells. Their number is at first reduced and then there follows a very temporary leukocytosis. There is an increase in the amount of hemoglobin and in the specific gravity of the blood without an increase in the number of red blood-cells. In the smallest animals the mature red blood-cells appear to be produced faster than normal by the loss of nuclei in the cells of which they are the mature form. This, while a natural process, is still a degenerative one, and that it is accelerated by the *x*-ray is in line with all the rest that we know about the properties of the latter. For instance, the hyperkeratosis which is a characteristic effect upon the skin is an exaggeration of the normal degeneration through which epithelial cells pass.

Effect Upon the Blood in Vitro.—Helber and Linser[1] have tested the effect of the *x*-ray upon blood in a test-tube. They find that a leukotoxin is developed in the serum which destroys the white blood-cells Blood-serum from a patient with leukemia ordinarily produces no effect if injected into a rabbit, but it produces a marked effect if the patient from whom the serum is obtained has been under *x*-ray treatment. In this case an examination of the rabbit's blood four hours later shows a considerable reduction in the number of white cells.

Heinecke's Experiments[2] on the Effect of the *x*-Ray Upon the Marrow of the Long Bones.—The destruction of white blood-cells in the bone-marrow, which takes place after several hours' exposure of the entire body of a guinea-pig, begins about two and a half hours after the commencement of the exposure. It reaches its maximum in ten or twelve hours and ceases after five or six days. All the different forms of leukocytes in the marrow are reduced in number, but the lymphocytes and non-granular myelocytes are the most affected; the eosinophile, mast cells, and giant cells are somewhat less affected, while the neutrophile polymorphic granular cells remain intact the longest. The broken-down marrow is capable of regeneration, and this begins at the end of about two weeks and is completed in three or four weeks.

Heinecke's observations go to show that in man the bone-marrow may react to the *x*-ray, but that undesirable or dangerous complications from the destruction of lymphocytes do not take place.

Changes in the Spleen.—The immediate changes in the spleen are inflammatory hyperemia and an increased collection of leukocytes, which takes place at the center of each follicle in the spleen. There are necrotic areas between the epithelioid cells of the follicle.

Secondary changes are more marked in the smallest animals, such as mice and rats, in which the entire pulp of the spleen may break down and the red blood-cells in the vessels of the spleen undergo granular degeneration.

In rabbits and dogs the secondary changes are limited to the follicle.

General Histologic Changes.—Generally speaking, the histologic effect of the *x*-ray is to produce an obliterative endarteritis in the superficial tissues and a destructive effect upon cells of a rapidly proliferating or embryonal type.

X-RAY BURNS OR RÖNTGEN DERMATITIS

Overexposure to the *x*-ray produces a change in the skin which may be very trivial or may be very serious indeed, and has even led to

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[1] Archives of the Roentgen Ray, March, 1906.

[2] Deutsch. Zeitsch. für Chirurgie.

fatal results. The danger is all the greater because there is no sensation of warmth or discomfort at the time. It may be produced by a single overexposure, the irradiation being too powerful, or too long continued, or the tube being too near the surface. The various instruments of precision for measuring the strength and quality of the x-ray are as necessary to proper dosage in examination and treatment as they are to successful picture making. The cumulative effect of successive exposures to the x-ray is a source of danger, especially to the operator, and very many of the x-ray specialists in this country have hands which are disfigured by chronic dermatitis. In the worst case the author ever saw the patient made and sold x-ray apparatus during the first year after its discovery, and was probably looking at or allowing others to look at the bones in his hand a large part of the time. The apparatus in those days produced a comparatively feeble radiance, so that no immediate effect was noted, but after several weeks of this reckless exposure he suddenly developed an inflammation and gangrene of the back of the hand and wrist. After several months of severe suffering the slough all came away leaving the tendons and the articular cartilages bare. Healing with deformity finally took place. Of a similar nature at the start were the recorded cases which years later formed the starting-point for epithelioma; and amputation and in some cases even death have followed.

There is nothing to indicate that an x-ray burn is any more likely to be followed by cancer than any other lesion of similar severity and chronicity.

Röntgen dermatitis may be of four different degrees:

(1) A mild temporary redness of the skin occurs without anatomic changes; it may not develop until two weeks after exposure and lasts for only three days or so.

(2) Quite a decided erythema with moderate itching and followed by desquamation of dry epithelial flakes, which may amount to a regular peeling of the affected region; no raw surface is produced and there is no pain; it develops about a week after exposure, and it is three or four weeks before the skin appears normal again; slight atrophy of the skin may remain permanently, especially if a dermatitis of this degree has been repeatedly produced.

(3) After a period of incubation of only two days a severe dermatitis with blistering occurs, and this is followed by some destruction of the deeper layers of the skin and ulceration which takes many months to heal. It is excessively painful until the sloughs have separated and it leaves a permanent scar.

(4) The most severe degree has a period of incubation lasting for one or two days; begins in much the same manner as the third degree, but it is soon evident that all the tissues have been destroyed, perhaps to a depth of ½ inch. The separation of the slough is very slow and painful, and the ulceration has very little tendency to cicatrize. If at all extensive it may take years to heal or it may remain as a chronic ulcer.

The Chronic Dermatitis of the Hands of x-Ray Operators.—This is a condition produced by frequently repeated exposures which individually would produce no effect. The lesion is somewhat of the character of a chronic eczema, and leaves the hands seamed, scarred, and discolored, with deformed and brittle nails, altogether such a condition as would preclude the use of the hand in aseptic surgery. A hand that has once developed this condition is for a long time thereafter more susceptible to the *x*-ray. Some operators believe that there is an acquired susceptibility to the action of the *x*-ray by which a strength of exposure, which would not have affected the operator at the start, may after months' or years' work with the *x*-ray suddenly produce a dermatitis. In Dr. Pitman's own recorded experience he suddenly developed a dermatitis affecting a large part of the body. The history of the use of the *x*-ray by very many operators, however, does not lend support to the theory of a gradually developed susceptibility, but one cannot too strongly caution those using the *x*-ray against a gradually developed false sense of security.

X-ray Warts.—After some years of *x*-ray work the skin of the operator's hands may present horny growths which are hard and black. Some of these project decidedly above the level of the skin and some are flat (Plate 14). They seem to be of similar structure to verruca senilis, and there is great danger of their developing into epithelioma. Drs. Kassabian and Leonard and Messrs. Greene, Bauer, and Baker are a few of our American *x*-ray workers who have lost their lives in this way. Their occurrence indicates that the operator has not taken sufficient precautions against exposing his hands. They may be removed by refraining from *x*-ray exposure and by applying 10 or 20 per cent. salicylic acid adhesive plaster. They are exceedingly prone to recur.

Another application is undiluted formalin (40 per cent. formaldehyd). A wooden match is dipped in it and the adherent drop is applied, to the wart alone, every three or six hours for two or three days. Smaller ones are killed in a few days, larger ones in a week. After exfoliation the skin should be unblemished; if not, repeat. If ulceration occurs, apply zinc oxid ointment or something similar.[1] The present author has applied this treatment to all of his own keratoses with permanent success in only one. The first applications produce no sensation; the later ones are decidedly painful.

Pyrogallic acid, 15 per cent. solution in flexible collodion, has been used by Dr. L. E. Lemen, of Denver (personal communication). After cutting off the wart almost to the bleeding-point an impervious coating is applied to the wart and extends slightly over the sound skin. The solution is applied night and morning for three days and often enough to maintain the coating for a week altogether. At the end of a week it is apt to become very much inflamed and painful, and requires a dressing of boric acid ointment, after relieving the tension by softening the collodion and removing it. A black pellicle of charred tissue forms which separates spontaneously a couple of weeks later, leaving a surface that looks like sound skin, but which may require one more course of treatment.

Surgical excision, if done in time, is usually permanently effective, and so is thorough destruction by fulguration or by radium.

Electrolytic actions take part in the production of Röntgen erythema, as pointed out by Bordier and Salvador,[2] but the present author believes that the *x*-ray is the exciting cause of the electrolytic action, and that there is no means of entirely preventing it except by interposing something entirely opaque to the *x*-ray.

The experiments of Strater, Kienböck, Oudin, and Scholtz seem to

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[1] R. L. Hammond, American Medicine, July, 1912.

[2] C. R. Acad. Sci., cxxviii, 1612, June 26, 1899.

PLATE 14

Röntgen-ray keratoses of the author's left hand. These had persisted for twelve years, but are now (February, 1915) being cured one after another by radium.

leave no room for doubt that radiodermatitis is due to the x-rays and not to electric discharges and other physical phenomena which take place around the tube.

PRECAUTIONS AGAINST RÖNTGEN RAY INJURIES

General Precautions.—Measure the intensity of the x-radiance your apparatus produces and learn the safety limit of its application. Practice upon inanimate objects until you have learned to produce a quality of x-radiance which will have the desired effect with a safe exposure. Remember the cumulative property by which several short exposures have as great an effect as a single prolonged one. Remember that the danger varies inversely as the square of the distance from the anticathode to the skin.

I. **Precautions in x-Ray Examinations.**—*A. Protection of the Patient.*—1. The use of the *fluoroscope* is fraught with the greatest danger, and I believe should be abandoned. If, contrary to my advice, it is employed on rare occasions, the strength of the radiance applied, and consequently the safety limit of exposure should be determined beforehand, and strict account should be kept of the actual exposure. A number of short exposures have an effect equal to one long exposure. Only the requisite part of the patient should be exposed. The x-ray should be filtered by passing through a thick screen of sole leather or aluminum. The anticathode should be 13 inches, and in most cases much further from the nearest surface of the body. The portions which are to be especially protected are the eyes, the testes, and the blood-forming organs such as the spleen. The greatest danger arises when a long examination is made or a long operation is performed, as for the removal of a foreign body under the fluoroscope.

2. In *radiography* the strength of the radiance employed and the safety limit of exposure should be determined beforehand and the fact of the cumulative effect of several exposures borne in mind. Cinematographs of a thick portion of the body requiring prolonged exposure, even with an intensifying screen, are contrary to my advice as involving a total exposure which may be dangerous. The effect of an x-ray exposure does not disappear for at least three weeks. A heavy sole-leather or aluminum screen should be employed and only the requisite part of the patient exposed. The anticathode should never be less than 13 inches from the nearest surface of the body, and should be considerably further away when a thick portion of the body is to be depicted. An intensifying screen, reducing the exposure to about one-tenth, should be used whenever a radiograph is to be made through a thick portion of a very large person, or when a number of radiographs are to be made through a thick portion of even a small person. The greatest danger arises when a more difficult case is attempted than ever before, and the most important thing is to place the tube at an increased distance from the skin. Leukemia and renal insufficiency necessitate caution as to any strong general exposure of the abdominal organs. The proper quality of x-ray is important; too low a degree of penetration has an excessive effect upon the skin with too little effect upon the plate, as so much is absorbed by the tissues. The unfluctuating current generator, producing x-rays of approximately uniform wave-length, is an element of safety in radiography by reducing to a minimum the admixture of soft rays with those of the proper penetration.

The best way to limit the application to the desired part of the patient in radiography is by means of an impervious case completely surrounding the *x*-ray tube, and having openings of adjustable size either plane or cylindric through which the *x*-ray is directed. The most satisfactory form of protective filter is a sheet of heavy sole-leather inside the impervious case and covering its orifice.

It is essential to be able to maintain the proper quality of radiance and to recognize changes in the *x*-ray tube, which destroy its effectiveness in producing a picture and by multiplying the length of time required add greatly to the danger of injury.

B. Protection of the Operator in x-Ray Examinations.—1. Never make direct use of the fluoroscope.

2. Never use any portion of your body as a test-object for measuring the quality or the intensity of the *x*-ray.

3. Do not use a fluoroscopic penetrometer, but always make a radiograph of the penetrometer in testing a new tube or new conditions.

4. Do not hold the film or plate in position yourself.

5. Never remain in the room with an unshielded *x*-ray tube in operation.

1. Fluoroscopy, during which the operator stands beyond the patient in a direct line with the *x*-ray, if many times repeated, means certain injury and frequently death. The danger to the operator may be obviated by his standing behind an impervious screen and viewing the fluoroscopic image in a mirror.

2. The physicians who have died from *x*-ray injuries have been victims chiefly of the habit of looking at the bones of the hand as a means of testing the quality and intensity of the *x*-ray. The manufacturers of the *x*-ray apparatus are often asked by prospective customers to allow the *x*-ray to shine through the chest or some other part of the body, so that the customer may see the fluoroscopic image. This has resulted in many lingering and painful deaths among the men who have brought the apparatus to its present efficiency. No physician ought ever to make such a request.

3. Many of the injuries to physicians have come from holding the fluoroscope in position for testing the radiance with a fluorometer. This practice should be abandoned and a radiograph made of such a test object as the Benoist radiometer.

4. The author regrets very much his former practice of holding the film in the patient's mouth in dental radiography. The individual exposures were of benefit to the patients, but their cumulative effect has permanently disfigured the operator's hands, and if the practice had been continued a cancer would have been produced.

5. Having the switches in a different room from the *x*-ray tube affords perfect protection. And the same object may be attained by having the *x*-ray tube enveloped in a case opaque to the *x*-ray and having the operator stand behind a lead screen and wear leaded spectacles, cap, apron, and gloves. Repeated exposures, even at a considerable distance, to the unshielded rays from an *x*-ray tube have in the case of a great many operators produced sterility and leukopenia, and has doubtless contributed to the fatal cases of *x*-ray cancer.

II. Precautions in Rontgen-ray Treatment.—(*A*) *Protection of the Patient.*—1. Do not give any Röntgen-ray treatment until you are able to measure and control the quality and intensity of the *x*-ray and know what exposure will produce a certain effect. A single measured dose sufficient to produce a more or less severe erythema is often desirable, but is very dangerous in the hands of the inexperienced.

2. Expose only the desired portion, shielding other parts by diaphragm or cylinders or by sheet lead or the like, fastened around the part to be treated.

3. Use a quality of ray adapted to the case—as nearly as possible all soft rays for a cutaneous lesion and all rays of greater penetration for deep lesions. The soft rays are obtained from a tube with a low degree of vacuum, and expecially with a converter producing a constant potential. The rays of greater penetration may be produced by a tube with a higher degree of vacuum, especially if excited by a converter producing a constant potential. Screens of aluminum or of sole-leather are often useful in arresting whatever soft rays may be present.

4. Use the cross-fire system in treating a deep lesion, so that no one portion of the surface will bear the entire brunt.

5. The deeper the lesion the further the anticathode should be from the skin. If the anticathode is only 4 inches from the skin, the latter will be twice as near the anticathode as a lesion 4 inches below the surface, and the skin would, even if distance were the only factor, receive a radiance four times as strong as the deep lesion. The percentage absorbed by the tissues overlying the deep lesion increases the difference in the effect, but is about the same whether the tube is near the surface or far from it.

6. Do not be deceived by the theory that any x-radiance is so entirely made up of hard rays that it can be safely applied with the tube very near the surface and in extremely large doses. Surface injuries and injuries to the tissues of the intestines have followed therapeutic applications based upon this theory.

7. The eyes, testes, ovaries, and hair are portions to be especially protected from accidental exposure.

(*B*) *Protection of the Operator in Röntgen-ray Treatment.*—The same precautions are absolutely necessary as in x-ray examinations.

The Prevention of x-Ray Dermatitis.—(1) The patient should not be exposed too long, too frequently, or to too strong a radiation. The strength of the radiation depends partly upon the energy given out by the x-ray tube and partly upon the distance at which it is placed, the effect diminishing as the square of the distance increases. For instance, at twice the distance from the anticathode the region exposed is submitted to only one-quarter the strength of x-ray. The length of time is, of course, dependent upon the strength of the application. For those who have not the different apparatus for measuring the strength of the application a good limit is nine minutes' exposure, at a distance of one foot from the anticathode, and a strength of x-ray which will permit the bones of the hand to be seen faintly at a distance of 2 feet from the anticathode. A stronger radiance would call for a correspondingly shorter exposure. Sometimes in treating the side of the neck it will be found that the shoulder is much nearer the tube than the part to be treated, and if so it would receive a dangerous amount of radiation unless shielded from the rays. In x-ray treatment it is always desired to produce some effect upon a certain area of tissue, and all other parts of the patient should be protected either by lead or other x-ray proof sheets, or by encasing the tube in some kind of localizing shield. There is some protection of the part exposed by interposing a thin metallic screen, like the author's screen for soft rays, or even by the clothes. Begin with smaller doses than indicated above and do not repeat them oftener than once in three days. Holzknecht's chromoradiometer furnishes a direct measure of the amount of radiation to which the region is exposed. Three Holzknecht units applied at one session will produce a visible reaction upon the face, and this limit should not be reached in radiography. But in radiotherapy it will be noted that certain cases require applications of 3 or 4 Holzknecht units, which, however, should not be repeated until the reaction has subsided. This may require an interval of three weeks or more. If the application is to be repeated once a week half the above dose is the limit, and if used more frequently a still smaller fraction of the dose is applied. A low vacuum-tube, giving a brilliant radiance, produces a much greater effect upon the superficial tissues than a tube with a high vacuum and greater penetration. The amount of radiance bears a certain relation to the strength of the current actually passing through the tube, as indicated by a milliamperemeter introduced between the coil and the tube, and it has been hoped that this one measurement would fully indicate the strength of the radiance, and that we could simply apply a strength of so many milliamperes for such a time at such a distance. This, however, is not sufficient. A Müller heavy target-tube, excited by a 12-inch coil, with a Caldwell interrupter giving about 5000 interruptions a minute, with a primary current of 9 amperes, and about 3 inches resistance in the tube, allows 1 ma. to pass. This is with considerable resistance in the rheostat; but with all the resistance cut out by turning the rheostat all the way, the current through the tube increases to 2½ ma. and the radiance becomes much more brilliant. We now connect the same tube in precisely the same condition as to vacuum with the prime conductors of a static machine, with six revolving glass plates 26 inches in diameter, and making about 300 revolutions a minute, the machine being in first-class working order. We find that 1 ma. is passing through the tube, but that the radiance is not nearly as powerful as when 1 ma. was passed through the tube by the coil.

The comparison is not quite a fair one—that is, comparing the effect of 1 ma. through the x-ray tube in conjunction with the coil and then the same in conjunction with a static machine. While it is not generally known, yet it is a fact which can be easily demonstrated, that a tube having a parallel spark-gap of 4 inches on an x-ray coil will only have a parallel spark-gap of ½ inch on a static machine.

In regard to the use of the milliamperemeter, Lewis Jones went into this matter very carefully, and his conclusions were that as long as the parallel spark-gap of the tube did not exceed 5 inches, the number of milliamperes through the tube gave a fair idea of its x-ray value with different tubes on the same apparatus, using the same rate of interruption and the same strength of primary current.

The milliamperemeter does not really give such information, so that another operator using a different make of apparatus would be able to absolutely reproduce the same effect, but it does give the individual operator a good guide as to the work of his tube, and if he keeps the rate of interruption constant, the primary current constant, and the resistance of his rheostat constant, then the meter will be of decided benefit, so that two facts are evident, the milliamperage passing through the tube is not by itself a sufficient measure of the amount of *x*-ray the patient is receiving, and an amperemeter on the primary circuit by itself is still less so. The only safe guides are wide experience or Holzknecht's chromoradiometer or some similar quantitimeter, combined with some good qualitimeter, like Walter's, Benoist's, or the present author's. The intensity of the radiance may be measured by the author's method, but, of course, we make use of the radiometer and spintremeter for determining the degree of vacuum. By the use of Holzknecht's chromoradiometer for determining the amount of *x*-ray, combined with a radiometer and a spintremeter to show the degree of vacuum of the tube, and hence the quality of the ray, and the author's method of measuring the intensity of the ray, we are able to administer the same doses as are recorded in the reports of workers in all parts of the world, and with apparatus varying wonderfully in efficiency. It is not necessary to note the change of color in the prepared pastil of the Holzknecht chromoradiometer for every exposure, but it is very desirable to experiment with it until you have determined for your own apparatus how many minutes' exposure at a certain distance and under certain conditions will produce 1, 2, or 3 Holzknecht units.

Merely as an example, it may be stated that a certain 12-inch coil with a Wehnelt interrupter, a primary current of 10 amperes, a tube of vacuum No. 6 (Benoist), was found to produce 4 Holzknecht units upon a surface 5 inches from the anticathode during an exposure of ten minutes.

(2) A screen for soft rays may be used. A thin sheet of aluminum, or of tin-foil, or a thick sheet of leather may be interposed between the *x*-ray tube and the portion to be treated. The rays which produce dermatitis are those which are of little penetration and which are consequently absorbed by the skin. A screen for soft rays will arrest these rays and allow only the more penetrating rays to reach the patient, and these have very much less effect in the direction of producing dermatitis. This protection is not absolute, however, and an overexposure is to be avoided.

(3) Geyser has suggested that the cause of dermatitis is not the *x*-ray, but an electrostatic condition which may be avoided by placing the tube directly in contact with the part to be treated. The author does not regard this as probably correct, and recommends avoidance of overdosage when the Röntgen ray is applied in this way.

RÖNTGENOTHERAPY

THE TREATMENT OF DISEASE BY THE *X*-RAY

It has been found by actual observation that the x-ray has a curative influence upon quite a variety of morbid conditions. It is not a sufficiently powerful bactericide to have any direct effect upon bacteria in doses which would be harmless to the tissues, and yet it is an excellent remedy in mycotic skin diseases. This is due to its depilatory action and to the slight stimulation it produces. It has a very markedly beneficial effect on tubercular processes, probably by an alterative and stimulating effect. And of a like nature is its effect upon rheumatic or gouty deposits about joints or nerves, and upon a variety of conditions, from colitis to keloid. It has a specific action in epithelioma and to some extent in every other form of malignant disease. It is a powerful analgesic.

The method of application is by allowing the x-ray to shine directly upon the affected part from a tube with a medium or low vacuum, with a strength and at a distance and for a length of time sufficient to produce a certain effect upon the tissues. Different plans may be adopted; the exposures may be mild and repeated every day or every two or three days, and a condition of reaction gradually reached and maintained; single large doses may be used sufficient to produce the degree of reaction required in that particular disease, and if necessary repeated after the three or four or more weeks which it takes for the reaction to develop and subside; or half doses may be used, each of which will excite a slight reaction, and the doses may be repeated every week or two. The method by frequently repeated small doses is the one which has been almost exclusively used in this country. It is much the safest and best method where one is uncertain as to the comparative intensity of the radiance applied by his apparatus.

The following is an example of dosage when no special means of measurement are available:

For doses repeated every three days the wall of the tube should be at a distance of 9 inches from the nearest exposed surface, the vacuum should be medium (equivalent to a 2½-inch spark-gap), and a penetration of about four or five thicknesses of tin-foil, the intensity such as to show the bones of the hand faintly in the fluoroscope at a distance of 2 feet from the tube, and the duration of exposure nine minutes. If only a small area is to be treated the tube may be brought nearer and the time regulated inversely as the square of the distance. Thus, at a distance of 3 inches from the wall of the tube or 6 inches from the anticathode or disk from which the rays radiate, an exposure of two minutes and a quarter would produce the same effect as nine minutes at a distance of 9 inches from the wall of the tube or 12 inches from the anticathode. In either case the neighboring parts should be protected by sheet lead or the like, or by using a localizing shield encasing the tube. This is equally important whether the distance be great or small. *X*-ray metal (Conley Foil Co., 521 W. 25th Street, New York) is very convenient for protection; it is a compound of lead and tin, and does not rub off on the skin as lead alone would. The thin weight is right for this purpose; it comes in rolls 1 foot wide and costs 10 or 15 cents a pound. Sheets of this foil, measuring 12×18 inches, may be put over the head and face, and other sheets with a hole, which may be made larger or smaller by turning back flaps, may be applied over the region to be treated. Large L-shaped pieces are useful in many places, as for exposing the shoulder while protecting adjacent parts. Other operators use a vertical screen of sheet lead with an adjustable orifice, and others sheet lead covered with rubber. The *x*-ray-proof rubber compound, made for gloves for protecting the operator's hands from dermatitis, makes a flexible and effective protection, but is rather expensive. With a substantial and readily adjustable *x*-ray tube stand, and a localizing shield which is opaque to the *x*-ray and almost completely surrounds the tube, the treatment of any part of the surface of the body is a very simple matter. Different diaphragms make the orifice through which the *x*-ray shines large or small, and vulcanite tubes are useful for introduction into the mouth or vagina.

Treatment tubes of various patterns have been designed by Cossar, of London, and Morton, Cleaves, and Caldwell, of New York, and by the author. In one type the bulb is large enough to avoid overheating and rapid change in vacuum, but is made of lead glass opaque to the *x*-ray while transparent to ordinary light. Opposite the anticathode there is a prolongation through which the *x*-ray passes, the extremity being made of glass which is transparent to the *x*-ray. There is a glass handle, by which the tube may be held in position for applying the *x*-ray to some small area like an epithelioma near the eye, or the prolongation may be passed into the vagina or mouth for the treatment of a cancer of the uterus or of the tonsil. In any case it is desirable to slip on a rubber cover, which is used only for a single patient.

In another type of treatment tube the bulb and prolongation are similar to those in the one just described, but there is no anticathode. The concave cathode directs the cathodal stream into the prolongation, and when this stream strikes the glass wall of the prolongation the *x*-ray is produced. Such a tube may be successfully used in the rectum, but, of course, the prolongation must be kept cool by a constant flow of water through an outer jacket.

Still another type has the anticathode near the end of the prolongation, directing the *x*-ray laterally, and, because of its close proximity to the glass, blackening the active part of the tube very quickly. Such a tube may have a heavily insulated wire returning from the positive pole or there may be no wire there. In the latter case the coil must not be a too powerful one and the positive pole of the coil is sometimes grounded. This type of tube is less desirable than the others.

A fourth type is the unipolar *x*-ray tube, constructed on much the same lines as the last described, without a positive wire. The cathode is connected with an Oudin resonator. The high-frequency and high-tension current produces a cathodal stream which impinges upon the anticathode and is then converted into the *x*-ray. These are made in small sizes for use in the mouth and get overheated if run for more than about half a minute at a time. As the anticathode is so near the surface to be treated, one or two short applications are enough. This tube, of course, acts also as a glass vacuum electrode for the application of high-frequency currents. Its practical value is problematic.

For general radiotherapy the heavy target Müller tube has proved very desirable. The essential feature of a tube for therapeutics is the ability to stand prolonged use with fairly heavy currents without overheating, and the possession of a regulating device by which the degree of vacuum may be readily and accurately adjusted. In using a coil, a primary current of more than 9 amperes will seldom be required for treatment, and with some interrupters a primary current of 6 or even 3 amperes is ample. Six amperes would be the current furnished by a Wehnelt interrupter in which only the tip of the platinum is exposed, and this is 1 millimeter in diameter, no resistance being interposed by the rheostat. A Caldwell or Simon's interrupter may have small or comparatively large holes between the two portions of liquid, or, in some cases, the size of the opening is adjustable. If the openings are small the interruptions are rapid and the strength of the primary current is perhaps only from 3 to 5 amperes without any rheostat, but the secondary current, as indicated by Gaiffe's milliamperemeter and by the *x*-ray, produced will be very good indeed. With larger holes the interruptions are slower, the noise produced is of a lower pitch, and the primary current may be as much as 10 or 12 amperes if no rheostat is used. This produces a brilliant *x*-ray and a much stronger secondary current than with the smaller and more rapid interruptions. But this strength is usually cut down by the rheostat until the secondary current and the *x*-ray are about the same as those with the more rapid interruptions. The primary current in this case remains quite heavy, perhaps 8 or 9 amperes. With a coil the greatest amount of self-induction in the primary winding is desirable for treatments. For several treatments in rapid succession it will be found necessary to have at least two tubes in readiness. The anticathode gets very hot from continuous use, gives out an injurious amount of radiant heat, and throws off particles of platinum which blacken the tube; and overheating results in a liberation of gas which lowers the vacuum beyond the useful limit. The Müller water-cooled tube runs for a long time without a change in its degree of vacuum with the strength of current suitable for treatment.

The important measurements in treatment are the degree of vacuum and the amount of *x*-ray. The first must be determined partly by means of the spintremeter, showing the length of spark which will pass between the poles of the *x*-ray coil rather than pass through the tube. The higher the degree of vacuum in the tube the greater is its resistance to the passage of the current and the longer is the spark it will back up. The other method of determining the degree of vacuum is by noting with the fluoroscope the degree of penetration of the *x*-ray produced. It is exceedingly dangerous to make a practice of looking at the bones in one's own hand, although they furnish an excellent test object. Far safer and more exact is the use of a radiometer in which the degree of vacuum is indicated by the thickness of metal through which the *x*-ray will shine. The present author's radiometer protects the face, hands, and chest of the operator as well as furnishing a scale of penetration (p. 1051). The same numbers in Walter's, Benoist's, and Tousey's radiometers all represent about the same degrees of penetration. The measurement of the amount of *x*-ray applied may be by Sabouraud and Noiré's radiometer or by Holzknecht's chromoradiometer (p. 1052), which show it by the change of color in a chemically prepared wafer corresponding to a certain number on a color scale. To give the same treatment recommended by some authority it is only necessary to use the same degree of vacuum and to continue the application until the prescribed number of Holzknecht units have been applied. This does not mean that it is necessary to use one of these pastils every time the *x*-ray is applied, or even that it is absolutely necessary for everyone using the *x*-ray to have the Holzknecht's chromoradiometer, but it is very desirable that everyone should know the strength of his apparatus in terms of these international units. Thus, one should know how many minutes' exposure it takes to equal 3 Holzknecht units with such a tube and vacuum, and such a primary winding, and such an adjustment of the rheostat and interrupter, and with or without spark-gaps, and at such a distance from the anticathode to the surface treated, and with such readings of the amperemeter on the primary circuit and the milliamperemeter on the wire passing from the coil to the *x*-ray tube. The efficiency of different tubes, coils, interrupters, transformers, and static machines varies so much that the strength of the application cannot be stated accurately in amperes or milliamperes. One may begin with the dose indicated on p. 1045, and gradually acquire a knowledge of safe and effective dosage, or one may watch the work of an expert long enough to be able to recognize the different qualities and intensities and to know their dosage; or, better still, one may have the different instruments of precision, and thus be able to more accurately duplicate the applications recommended by workers in different parts of the world. Attention to detail is absolutely essential in *x*-ray work, and the operator should record every condition under which each exposure to the *x*-ray was made.

THE TECHNIC OF RÖNTGEN THERAPY

An 8- or 12-inch coil may be used, and its primary winding should be such as to give a variable self-induction, and usually the greatest amount of self-induction is used. The details of this and other technical points are more fully gone into in the section on Radiographic Technic. A Wehnelt interrupter with a platinum rod 1 mm. in diameter and with just its tip exposed, or a mechanical wheel interrupter, or a Caldwell-Simon interrupter with comparatively small holes will be found to give the best current. This should have rapid interruptions and a strength of 2 to 4 or 5 amperes when properly regulated by the use of the rheostat. A transformer with high-tension rectifier or an unfluctuating current generator may be used, but with a much weaker current than for radiography. The intensity of the *x*-ray itself should be measured with a certain strength of current. It will be easy to duplicate the conditions at any time. A 7-inch tungsten target tube, or water-cooled tube (Fig. 478), are very satisfactory; the vacuum should be medium or low, resistance 1 or 2 inches, and radiometer 2 to 4 Benoist. The current passing through the tube itself should be 1 to 3 ma. Spark-gaps between the coil and tube are usually not required, but should be used if the tube shows signs of inverse discharge, especially by the absence of a sharp equatorial line dividing the light from the dark hemisphere. (The two positive terminals are connected by a wire, or only the anode or the anticathode may be used to get the best radiance.) The tube should be so placed that its long axis is parallel to the surface to be treated, the wires are in this way as far as possible from the patient. The radiance is equally intense in practically all directions in front of the anticathode.

The neighboring parts should be protected by the Ripperger, Friedlander, or similar shield, or by sheets of x-ray metal, or by the use of x-ray tubes made of lead glass opaque to the x-ray except in the direction of the part to be treated.

A stand should be used substantial enough to stand the weight of the tube and shield, and with arrangements by which the tube may be readily adjusted in any position. Such a one is Ripperger's, slightly modified by the present author.

The Dosage of the x-Ray.—This is a matter which is influenced by various considerations which produce the greatest possible difference in the intensity of the radiation from different apparatus and from the same apparatus differently manipulated. Two entirely different methods of administration are in use. In one, moderate doses are given at intervals of one, two, or three days until a reaction of the desired degree is gradually produced. The other method requires a knowledge of the dose which will produce the necessary reaction with a single application. It is comparatively easy to define the dose for the first method; it is an exposure of one to two minutes at 5 inches from the anticathode or four to eight minutes at 10 inches, using the apparatus and adjustment described on p. **1046.**

The dose in the second method is equally easy to define, but requires a special apparatus for its measurement or very great experience and judgment in applying the x-ray. One special apparatus is Holzknecht's chromoradiometer. A chemically prepared pastil is exposed at the same distance from the tube as the part under treatment, and the application is continued until the pastil has changed color to correspond with 1, 2, 3, 4, or possibly 5 of the color scale. This indicates that the irradiation has amounted to a corresponding number of Holzknecht units. One H. is about a third of the amount of the x-ray that must be applied at one session in order to produce a visible reaction on the face; 3 or 4 H. is a full dose, and would not be repeated until the reaction had developed and subsided, usually not for several weeks; 5 H. is a very large dose, sometimes required in cancer cases; 2 H. is a half dose, which may be repeated every two weeks and will maintain a constant moderate reaction. In every case it is necessary that the tube should be of the proper degree of vacuum, although Holzknecht thought originally that a certain number of units indicated by his instrument would produce the same effect, whether the vacuum were high or low. This has not proved to be the case, but the apparatus does measure the amount. Without the chromoradiometer this would require a calculation in which the distance and duration of exposure would be the simplest, and the intensity of the irradiation would be the most complex, factor.

Gaiffe's Measurement of x-Ray Dosage.[1]—His method employs a piece of barium platinocyanid screen, which is placed upon the surface of the body near the part under treatment. A part of the screen is shielded from the x-ray by different thicknesses of some such material as lead-

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[1] Comptes Rendus Acad. des Sciences, Paris, vol. cxlii, p. 447.

foil. The general surface soon loses its brilliancy of fluorescence, while the parts which are shielded do so more slowly. The latter, however, is only a matter of time. The unshielded part undergoes a maximum loss of brilliancy which is attained by the different shaded portions in succession. To see what amount of x-ray has been applied the barium platinocyanid screen is removed from behind the shield and held up to the x-ray. Some parts of the shaded portion may be found to have exactly the same loss of brilliancy as the unshaded portion; the number of parts which have attained the maximum loss of brilliancy shows the amount of x-ray applied. Such an apparatus should be standardized so that each unit would be equal to 1 Holzknecht unit or a certain fraction thereof.

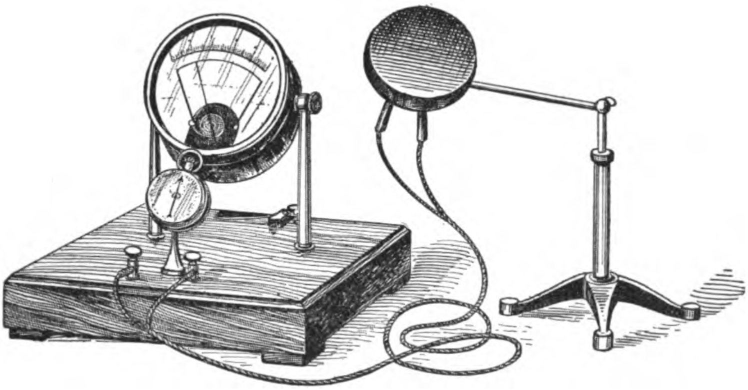

Fig. 737.—Selenium cell intensimeter for x-ray dosage.

Selenium Cell in x-Ray Measurement.—Geo. C. Johnston, in America,[1] and Luraschi[2] describe a method by which the varying resistance of a selenium cell when exposed to the x-ray is used as a measure of the intensity of the latter. The general arrangement is shown in Fig. 738. A dry-cell battery generates a current the strength of which is indicated on the milliamperemeter and is dependent upon the resistance in the selenium cell and in a certain adjustable additional resistance; the latter is regulated so as to have the indicator point to the zero mark on the scale. When the resistance of the selenium cell is lessened by exposure to the x-ray the milliamperemeter registers an increased current. The selenium cell is set at a point near the x-ray tube, and the battery, resistance, and milliamperemeter may be at a distant position, where the operator may be protected from the x-ray by the interposition of a brick wall if this is desired. Any change in the amount of current registered by the milliamperemeter would, of course, indicate a fluctuation in the amount of x-ray being generated by the tube, and would cause the operator to take the necessary steps to regulate the tube. The use of the apparatus as a measurement of dosage is more or less empiric. The selenium cell is set at a certain distance from the x-ray tube and the amount of deviation produced in the milliamperemeter is noted. A Sabouraud and Noiré tablet for radiometry or a Holzknecht tablet is exposed for the time necessary to produce a specified number

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[1] Transac. Amer. Roentgen Ray Soc., 1906.

[2] Arch. d'Electricité Medicale, Jan. 10, 1908.

of Holzknecht units. This furnishes a scale from which the operator can judge of the number of units or fractions of units applied in any number of minutes. It is necessary to place the selenium cell at the same distance as in determining the standard, and to regulate the intensity of the x-ray so that it will produce the standard deviation in the milliamperemeter, and then expose the patient for the necessary number of minutes to produce the required dosage.

Bordier's Unit I.—It is the amount of x-ray which, acting upon a 2 per cent. solution of iodoform in chloroform, the rays being normal to the surface—the surface being 1 square centimeter and the depth 1 centimeter—will liberate $\frac{1}{10}$ milligram of iodin.

3.5 I is about equal to 5 H. (5 Holzknecht units).

Bordier's Radiometric Tints.—These depend upon the change in color undergone by barium platinocyanid at half the distance from the anticathode to the skin.

Bordier's tint 1 (clear yellow) equals 2 I. (I equals the quantity of x-ray which will liberate $\frac{1}{10}$ milligram of iodin in 1 cc. of Freund's solution. The latter is a 2 per cent. solution of iodoform in chloroform and becomes red when exposed to the x-ray). His *tint 2* (sulphur yellow) equals 3½ I. His *tint 3* (gamboge) equals 5½ I. His *tint 4* (chestnut) equals 10 I.

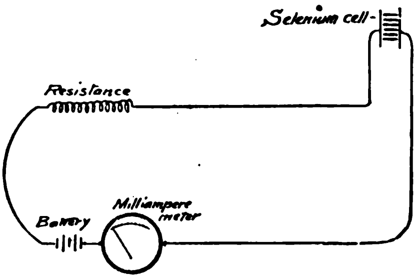

Fig. 738.—Principle of selenium cell in x-ray dosage.

Contremoulin's Radiophotometric Method.—This consists in a method for comparing the illumination produced in a barium platinocyanid screen with that of ordinary light of different candle-powers.

Schwartz's Method of Radiometry.—This is to determine by volume the amount of calomel precipitated from a solution of ammonium oxalate and mercury bichlorid when exposed to the x-ray.

Castex modifies Schwartz's method by taking the weight of the precipitate instead of its volume.

Curchod's Method of x-Ray Dosage by a Voltameter in the Secondary Circuit.[1]—The instrument is like a pipet containing 15 cc., but with its lower end bent up so as to hold about 10 cc. The latter is open at the top. Platinum wires allow the secondary current to pass through the acidulated water in the closed arm of the pipet, and bubbles of mixed hydrogen and oxygen gas are liberated and accumulate at the top. The number of cubic millimeters of gas liberated while a Sabouraud and Noiré barium platinocyanid pastil is changed to tint *B* affords a unit which may be subdivided at will for future treatments without having to use the pastil each time, and it is useful by giving smaller fractions than the Sabouraud and Noiré method.

Bergonie's Actinometer.—This is an instrument for measuring the intensity, in actinic rays, of the various lights used in phototherapy and also of the x-ray. A hollow metal cylinder has an opening at one end which fits closely over the observer's eye and at the other end a disk half of which is opaque and black, the other half being coated with·

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[1] Arch. d'Electricité Medicale, Jan. 10, 1907.

barium platinocyanid. This end of the tube is closed by a sheet of quartz crystal, and the whole tube is moved back and forth by means of a rack and pinion in the dark box which surrounds it. This box is filled with a solution consisting of:

Copper sulphate ($CuSO_4$)	100 gm.
Aqua ammonia	200 cc.
Water	500 cc.

Opposite the end of the tube there is a quartz window 4 cm. in diameter. The light to be tested passes through this window, through the liquid, and through the quartz window at the end of the tube, and produces a greater or less fluorescence in the barium platinocyanid at that point. The solution with which the box is filled absorbs the actinic rays, and if the layer of liquid is thick enough it will entirely prevent the visible fluorescence of the barium platinocyanid. In applying the test the actinometer is held at a distance of 2 meters from the source of light, and the tube is moved back and forth in the box so as to measure the thickness of liquid required to suppress the fluorescence.

Tested in this way an arc light for phototherapy (current of 110 volts, 20 amperes) suffered absorption of all its actinic rays by 58.5 mm. of the solution; a large arc lamp for stereopticon purposes with vertical carbons (110 volts, 20 amperes), by 55.5 mm.; a small arc lamp for the stereopticon (110 volts, 7 amperes), by 42.5 mm.; the direct rays of the sun at 4:30 P. M. in July, by 79.5 mm.

This method is applicable to all varieties of phototherapy, including the ultraviolet ray from Geissler tubes. It has not yet been determined whether this furnishes a reliable guide to the comparative intensity of the x-ray, but it certainly seems less convenient than the ordinary radiometer dependent upon the thickness of a metal which the x-ray will penetrate. This is indicated upon a barium platinocyanid screen or upon a photographic plate in the cases in which it is desired to produce an indisputable record of the penetrating quality of the ray employed in making a radiograph.[1]

Kienböck's Quantitometer for Measuring x-Ray Dosage.—The apparatus used by this Vienna radiologist[2] employs little slips of not very sensitive bromid paper of a standard make. One of these is wrapped in black paper and exposed at the same time and distance as the patient; then it is placed in a developing solution of standard strength for a standard time (one minute) inside a little portable dark room. The developed paper is at once compared with a scale of different shades of paper. The number marked on the shade which the test paper matches indicates the number of Kienböck units applied. Each unit is called "x," and is equal to ½ H., so that this method is twice as delicate as the Holzknecht method. The developing-box is just large enough for the hands to work inside of, a dark sleeve being fastened around the wrist to exclude ordinary light. Ruby glass windows admit red light and allow the operator to see what he is doing. Possible sources of error are a change in the sensitiveness of the paper from age or atmospheric conditions and a change in the activity of the developing solution.

Milton Franklin's electroscope for the dosage of the x-ray consists of a delicate electroscope, which may be placed at a measured distance

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[1] Arch. d'Electricité Medicale, Bordeaux, France, Jan. 15. 1903.

[2] Le Radium, p. 125, April, 1906.

from the tube. The electroscope is first charged and the rapidity of discharge is noted by means of a magnifying glass. A circular metal disk forms a shield for the operator.

The Sabouraud and Noiré Radiometer.—This is described more fully on p. 1073. A little tablet coated with barium platinocyanid is exposed at half the distance from the anticathode to the surface to be treated during the *x*-ray application. When the original apple-green color has changed to *tint B*, a brownish yellow, a full dose of 5½ Holzknecht's units has been applied.

Haret's Carrier for the Sabouraud and Noiré Radiometer.[1]—This apparatus (Fig. 739) is employed by the author and is made of hard rubber and is clamped to the *x*-ray tube near the cathode. It carries one of the Sabouraud and Noiré tablets, which may be adjusted at half the distance from the anticathode to the patient, and also a dark brownish-yellow tablet for comparison. During the exposure the radiometric tablet is protected from ordinary light by a sheet of black paper, but occasionally the tablet may be turned back for comparison with the test object. When it has turned the same dark yellow color as the latter it is called tint *B*, which means that a full therapeutic dose has been applied, causing all the hair of the scalp to fall out from a single treatment. This is equal to 5½ Holzknecht units.

It is supposed to be necessary only to simply continue the exposure to the *x*-ray until the test object has undergone the standard chemic change as indicated by its color. Practically, it is found that a variety of conditions, atmospheric and otherwise, render it difficult to apply these methods every time the *x*-ray is turned on. At the same time, these methods, applied under ideal laboratory conditions, are excellent for use in standardizing other more practicable methods of dosage.

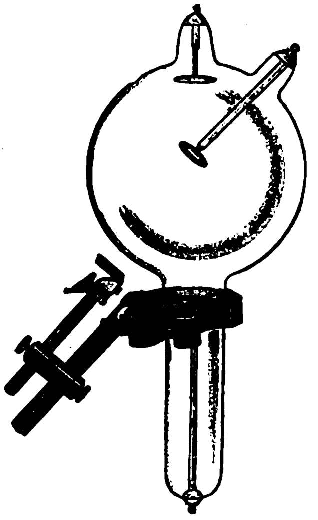

Fig. 739.—Haret's carrier for the Sabouraud and Noiré radiometer.

The practical object to be sought is a means of measuring the intensity of the radiation in terms from which one may in an instant calculate the duration of exposure at a given distance required to produce a certain effect on the tissues if rays of a certain quality are employed.

Tousey Units of x-Ray Power and Quantity.—1 *Tousey* is the *x*-ray power which will produce upon kodak photographic film an effect equal to that of 1 candle-power of carbon filament incandescent electric light of the usual brightness, applied for the same time and at the same distance. Different films and plates present different ratios of sensitiveness to light and the *x*-ray. Kodak film is selected because universally obtainable.

1 *Tousey meter second* is the quantity of the *x*-ray which will produce upon kodak photographic film an effect equal to that of 1 candle-power

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[1] Arch. d'Electricité Medicale, Jan. 10, 1905.

of carbon filament incandescent electric light applied for one second at a distance of 1 meter.

Equivalents of Tousey Meter Seconds.

100 Tousey meter seconds of about 6 Benoist penetration = 1 H.
500 Tousey meter seconds of about 6 Benoist penetration = 5½ H.
500 Tousey meter seconds of about 6 Benoist penetration = Tint B. Sabouraud and Noiré.
500 Tousey meter seconds of about 6 Benoist penetration = Tint 1 Bordier.
500 Tousey meter seconds of about 6 Benoist penetration = 3 or 4 units I Bordier-Galimard.
500 Tousey meter seconds of about 6 Benoist penetration = 625 Guilleminot units, M.
500 Tousey meter seconds of about 6 Benoist penetration = 10 X (Kienböck).
500 Tousey meter seconds of about 6 Benoist penetration = 3.5 kaloms (Schwartz).
500 Tousey meter seconds of about 6 Benoist penetration = An ordinary erythema dose.
750 Tousey meter seconds of about 6 Benoist penetration = An extreme erythema dose without ulceration.

This is a valuable means of gauging the intensity of the *x*-ray, and so determining its safety limit and the exposure required to make a picture in radiography and its dosage in therapeutics.

Measurement of the Tousey Power.—Separate portions of a kodak photographic film are exposed to 1 meter second of incandescent electric light and to various numbers of meter seconds of the *x*-ray which is to be tested. Then the entire film is developed in the regular full-strength photographers' tray-developing solutions, not the slower tank-developing solutions, for ten minutes in perfect darkness. The effect of light and *x*-ray appear in different lengths of time and it is essential that both effects should be fully developed. Stopping after two or three minutes' development would give a misleading ratio.

Do not attempt to make any such comparison as to say that the photographic effect of 1 meter candle-power second of electric light seems to be twice as great as that of 1 meter second of the *x*-ray to be tested. The only reliable method is to try different *x*-ray exposures until one is obtained which will exactly equal the photographic effect of 1 meter second of electric light. Thus, we may find that two seconds exposure to the *x*-radiance to be tested at a distance of 1 meter (*i. e.*, 2 meter seconds of that particular *x*-radiance) produce a photographic effect equal to 1 meter second of electric light. In that case the *x*-radiance is said to be of ½ Tousey power.

The *x*-ray and ordinary light both diverge in every direction, and their intensity varies inversely as the square of the distance and directly as the intensity of the source. One meter candle-power second of electric light may, therefore, consist in the light from a 16-candle-power lamp applied for one second at a distance of 4 meters, or a 4-candle-power lamp for four seconds at a distance of 4 meters.

The *x*-ray test application had usually better be made at a standard distance of 1 meter, and its power is inversely proportional to the number of seconds required to produce 1 Tousey meter second (*i. e.*, to equal the photographic effect upon kodak film of 1 meter second of carbon filament incandescent electric light of the usual brightness).

To measure the most powerful *x*-radiance, which can only be turned on for a fraction of a second, the best way is to make three exposures of one-quarter second each, at a distance of $\frac{1}{4}$, $\frac{1}{2}$, and 1 meter. Calculating from the inverse square of the distance, an exposure of one-quarter second at $\frac{1}{4}$ meter is the same as sixteen-quarters or four seconds at 1 meter; and one-quarter second at $\frac{1}{2}$ meter is the same as one second at 1 meter. Guided by the result of the first film, other distances may be employed until the exact equivalent of 1 candle-power meter second is found.

Application of this Method to Secure Safety in Radiography.—The radiographer should measure the intensity of the radiance which he habitually uses for certain classes of work. If this is of 1 Tousey power, then 500 meter seconds (or fifty-five seconds at $\frac{1}{4}$ meter from the anti-cathode to the skin) would be an erythema dose. This exposure at one time, or divided among several radiographs within a week or two, would produce an *x*-ray burn. If one's technic is so poor or the subject so difficult that the examination cannot be completed without approaching this safety limit, the attempt should be abandoned.

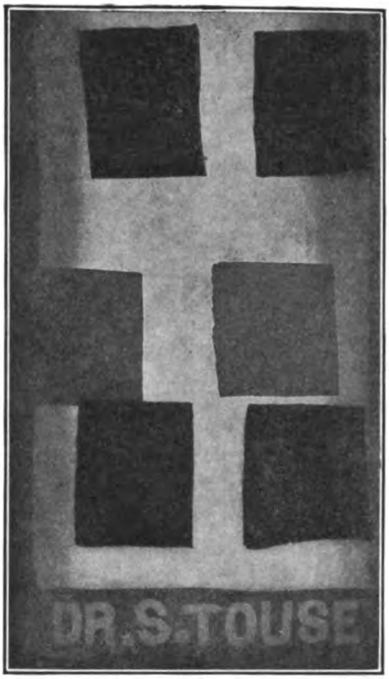

Fig. 740.

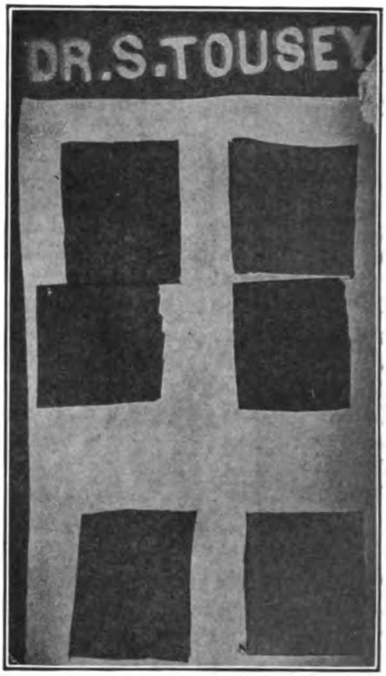

Fig. 741.

Figs. 740, 741.—Tousey measurement of *x*-ray power. Two middle squares exposed to 1 candle-power meter second of incandescent electric light. The others exposed to the *x*-ray for different times at a distance of 1 meter. The effects, which are exactly equal to the standard 1 candle-power meter second, enable one to calculate the Tousey power of the *x*-ray.

X-ray of 1 Tousey power will make most radiographs in a fraction of a second with or without an intensifying screen, depending upon the difficulty of the case.

The Tousey Method of Dosage in Röntgenotherapy.—For surface lesions no filtering screen is used either for previously measuring the Tousey power with a kodak film or during the treatment. If the *x*-radiance has

Erythema Exposures of x-Ray of Various Radiographic Strengths.

Tousey Power.	Anticathode to Skin.		Minutes.	Seconds.
	Meters.	Inches.		
1	⅓	13	....	56
	⅙	6½	....	14
⅓	⅓	13	2⅘	
	⅙	6½	....	42
⅙	⅓	13	5⅗	
	⅙	6½	1⅓	
1/10	⅓	13	9⅓	
	⅙	6½	2¼	
1/20	⅓	13	18⅔	
	⅙	6½	4½	

a penetration of about 6 Benoist and 1/60 Tousey power, then sixteen minutes' exposure at 6½ inches from the anticathode to the skin will be an erythema dose of 500 Tousey meter seconds. Other distances and their erythema doses are given in the following table:

Erythema Dose of x-Ray in Ordinary Therapeutic Strength.

Distance from anticathode to skin.		Tousey power.	Minutes.
Meters.	Inches.		
⅓	13	1/60	56
⅓	13	1/50	47
⅓	13	1/40	37
⅓	13	1/30	28
¼	9⅓	1/60	31
¼	9⅓	1/50	25
¼	9⅓	1/40	20
¼	9⅓	1/30	15
⅕	8	1/60	20
⅕	8	1/50	16⅔
⅕	8	1/40	13⅓
⅕	8	1/30	10
⅙	6½	1/60	14
⅙	6½	1/50	11⅔
⅙	6½	1/40	9⅓
⅙	6½	1/30	7
1/7	5½	1/60	10
1/7	5½	1/50	8⅓
1/7	5½	1/40	6⅔
1/7	5½	1/30	5
⅛	4⅞	1/60	8
⅛	4⅞	1/50	6⅔
⅛	4⅞	1/40	5⅓
⅛	4⅞	1/30	4
1/9	4⅓	1/60	6
1/9	4⅓	1/50	5
1/9	4⅓	1/40	4
1/9	4⅓	1/30	3

For making the test, flat kodak films measuring 2½×3½ inches are bought from the Eastman Kodak Co., Rochester, N. Y., U. S. A. One

TABLE OF RADIOGRAPHIC EXPOSURES.

13 Inches from the Skin.

	Transformer with maximum discharge.	Transformer yielding 3 Tousey power (about 90 kilovolts and 150 ma.).	Transformer yielding ¾ Tousey power (about 70 kilovolts and 25 ma.).	Induction-coil yielding 1/14 Tousey power (about 22 amperes and 8 ma.).	Static machine yielding ¼ Tousey.	Portable coil yielding 1/12 Tousey.	Best intensifying screen.	Dose applied to the skin during one exposure.	
								Tousey M. S.	Fraction of erythema dose.
Child's hip, 4 inches thick.	Fraction of second.	1 second.	7 seconds.	42 seconds.	42 seconds.	126 seconds.	Reduces time to 1/10 normal exposure.	20	1/25
Adult abdomen, frontal sinus, or hip............	Fraction of second.	1½ seconds.	10 seconds.	60 seconds.	60 seconds.	180 seconds.	Reduces time to 1/10 normal exposure.	30	1/15
Adult face, chest, or knee..	Fraction of second.	1 second.	5 seconds.	30 seconds.	30 seconds.	90 seconds.	Reduces time to 1/10 normal exposure.	15	1/30
Adult ankle or elbow......	Fraction of second.	½ second.	2 seconds.	10 seconds.	10 seconds.	30 seconds.	Reduces time to 1/10 normal exposure.	5	1/100
Adult hands.............	Fraction of second.	¼ second.	1 second.	5 seconds.	5 seconds.	15 seconds.		2 1/12	1/400
Teeth upon Eastman positive cinematograph film held inside the mouth[1]..	Fraction of second.	½ second.	4 seconds.	25 seconds.	25 seconds.	75 seconds.	Cannot be used.	12	1/40

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[1] For very large persons with a stronger exposure, the anticathode should be *more than 13 inches* from the skin.

of these is placed in a black envelope which has two small windows cut in it, each of which can be opened separately by turning back a flap. These preparations are made in the dark room and preferably at night. A 4-candle-power lamp is left burning in the outer room at a distance of 4 meters and is covered by a black paper except at the side toward the dark room. Having opened one of the flaps in the envelope in the darkness, the opening is covered by pressing that surface against the operator's clothes until the door is opened, and then, stop-watch in hand, the envelope is held toward the light 4 meters distant for four seconds. The front of the envelope is pressed against the operator's chest to prevent further exposure and the door closed; then the portion just exposed to light is covered and another portion gotten ready by turning back the other flap. Two portions are exposed to 1-candle-power meter second of incandescent electric light separately, so that one acts as a control as to the accuracy of the other. After the exposure to light the entire envelope is placed inside a larger black envelope.

A number of such packets may be prepared at once and kept in a lead-lined box ready for the *x*-ray exposure. For the latter purpose, a thick sheet of lead is folded around the film packet like the cover of a book. The openings in the front cover are closed by lead flaps which may be turned back separately, exposing different parts of the film to the *x*-ray for various numbers of seconds at a distance of 1 meter. On developing the film 6 squares will be found to be darkened, two by electric light and four by *x*-ray. It is essential that a large part of the film shall be protected from both, and the fact that this portion does not darken in the developing solutions shows that the darkening of the different squares is not due to any accidental exposure during the process of development. It will not be safe, for instance, to expose the film to the ruby light in the dark room during development.

Tousey Power of the x-Ray from Various Generators.—A 12-inch induction-coil, with a wheel interrupter and a primary current of 110 volts and 5 amperes and a secondary current of $1\frac{1}{5}$ ma., produces an *x*-ray of about $\frac{1}{80}$ Tousey.

The same coil, with a Wehnelt interrupter and a primary current of 110 volts and 18 amperes and a secondary current of 8 ma., produces an *x*-ray of about $\frac{1}{14}$ Tousey.

A static machine actuated by a current of 220 volts and 25 amperes and sending about $6\frac{1}{2}$ ma. through the *x*-ray tube produces an *x*-ray of about $\frac{1}{6}$ Tousey power.

An interrupterless transformer or a high-tension direct current generator produce from $\frac{1}{6}$ to 1 Tousey for radiographic work, and may be reduced to $\frac{1}{80}$ Tousey for treatment or fluoroscopy.

Villard's Instruments for Measuring the Intensity and Quality of the x-Ray.—These depend upon the ionizing effect of the ray. The radiosclerometer is of the nature of a quadrant electrometer, which is connected with a source of uniform potential, such as a direct 110-volt of electric-light circuit. The *x*-ray can reach different parts of the apparatus through an aluminum and a silver screen. The deviation of the electrometer indicates the ratio between the radiation transmitted by the silver and by the aluminum. This is dependent upon the quality of the ray and not upon its intensity.

The radioquantitometer registers by clockwork the number of times that an electroscope, connected with the 110-volt direct current, becomes charged and discharged during the total time that the patient is exposed to the x-ray. The electroscope in this case is of the general construction of a quadrant electrometer.

Each of these two instruments looks like a milliamperemeter, and is intended to be placed at the same distance from the x-ray tube as the patient.

Influence of the Rate of Interruption in the Primary Current Upon the Quantity of x-Ray Produced.—In an experiment by Bordier,[1] with the same strength of primary current and the same quality of x-ray, the Sabouraud and Noiré radiometer absorbed 1 tint in nineteen minutes with 1938 interruptions per minute; and required only ten and a half minutes when the interruptions were at the rate of 3544 per minute.

This has a very important bearing upon the subject of dosage in radiotherapy. It does not impair the value of any of the measurements which depend upon the change produced in a chemic substance, but it does affect measurements based, like the author's, upon brilliancy of illumination, or, like Johnston's, upon the resistance of a selenium cell. The last two methods and several others might give different results with different types of apparatus sending impulses through the x-ray tube at different rates per minute.

The use of the *static machine* for x-ray treatments is entirely satisfactory if the machine is powerful enough and in good working order. Measured by a milliamperemeter the current passing through the tube will be found not to be much over 1 or 2 ma. at the most, and the fact that the amperage is very low makes the heating of the anticathode very slight. In fact, the heat is dissipated as fast as it is produced, and so the bulb may be used for hours without getting hot and without material change in degree of vacuum. It is on this account that the less expensive, but equally well made, light anticathode tubes are used with the static machine. The small amount of current passing through the tube causes the intensity of the ray to be so slight that much longer exposures are required than with a coil. Experience in radiography shows that the time must be about five times as long, and in fluoroscopy the safe time of exposure is so long that there is danger of forgetting that there is a limit beyond which there is the risk of a burn. In radiotherapy with the static machine, in the absence of special apparatus, like Holzknecht's chromoradiometer, the dose which may be administered every two or three days may be stated to be eight to fifteen minutes at a distance of 10 inches from the anticathode. This is with a machine having twelve or sixteen revolving glass or mica plates, 32 inches in diameter, and with a tube of medium or high vacuum, backing up a spark of 3 to 6 inches. Spark-gaps are generally useful when working with a static machine.

THE X-RAY IN THE TREATMENT OF MALIGNANT DISEASE

The x-ray most assuredly has a selective action upon the atypic, rapidly developing cells which constitute the essential part of most malignant neoplasms. There is reason to believe that the soft rays, those with the least penetrating power, produce the most beneficial effect, and it is very certain that the diseases, like epithelioma, in which the lesion is often a purely surface one, are much more amenable to this

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[1] Arch. d'Electricité Medicale, Jan. 10, 1907.

method of treatment than are the carcinomata and the sarcomata with deep-seated lesions. Still, even these are almost always favorably affected, and in some cases a cure may be produced. The effect generally sought is not one of destruction *en masse,* but of molecular change and elimination. It is seldom wise to produce an ulceration by the application of the *x*-ray in treating malignant disease. In some cases the elimination of the products of a degenerative process produced by *x*-ray treatment of a large malignant growth will cause a sort of toxemia. This is a temporary matter and its nature is discussed in the chapter on the physiologic effects of the *x*-ray. It may furnish an indication for less vigorous treatment for a time; it does not indicate a tendency on the part of the treatment to produce metastases and a general dissemination of the disease. The latter question has been most thoroughly studied. In certain cases which are submitted to *x*-ray treatment while the disease is still purely local, and before any metastases have taken place, the *x*-ray effects either an actual or a symptomatic cure. In other cases metastases have already occurred and may sometimes be demonstrated by *x*-ray examination in the mediastinal glands, although symptomatically the disease may still appear to be a local one. In such a case *x*-ray treatment may produce a brilliant effect upon the local lesion, and this may be accompanied by a most gratifying increase in health and strength. Then after a period of, it may be, seemingly perfect health lasting for several months, the patient shows evidence of the systemic involvement, and a fatal termination very quickly ensues. In such cases the *x*-ray has not caused the dissemination of the disease, it has simply been unable to prevent it. Much benefit may be accomplished in such cases in the direction of removing, controlling, or preventing the recurrence of a local lesion and delaying the occurrence of metastases and death, and, except for intrathoracic and intra-abdominal cancers, a considerable percentage of cures may be expected. *X*-ray treatment before and after an operation upon an external growth, such as a carcinoma or sarcoma of the breast, has a decided tendency to prevent recurrence. The same holds good of cancers of the neck of the uterus, a part which can be reached directly by the *x*-ray, but here internal involvement has practically always occurred before *x*-ray treatment is begun. Valuable and effective as it is in these cases it will probably not save the patient's life. The beneficial effects of the *x*-ray in cancer are the relief of pain by an immediate action, the cure or control of a local lesion, a directly beneficial effect upon the general health, the prevention of recurrence if internal involvement is not already present, and the cure or control of external glandular metastases. *X*-ray treatment is indicated at every stage of a cancer, but it should be an adjunct to and not a substitute for surgery in the majority of cases.

The technic consists in exposing not only the affected region, but a considerable surrounding area, to the rays from a tube with a low vacuum (resistance 1 or 2 inches, radiometer 2 or 4) for surface lesions, and a medium vacuum (resistance 3 inches, radiometer 5 or 6) for those more deeply seated. It is absolutely necessary to produce a certain degree of reaction, but probably the best results are obtained when this occasions only redness and a dry desquamation without ulceration. Cases of deep-seated cancer, as of the breast, in which the disease has not produced ulceration, are as amenable to the influence of the *x*-ray as cases in which ulceration has occurred. The same two methods are available for cancer that are used for other cases. By one method moderate doses (nine minutes at 10 inches from the anticathode, with an intensity which shows the bones of the hand faintly at 2 feet; or Wehnelt interrupter with tip of platinum 1 mm. in diameter exposed, primary current 4 amperes, current through x-ray tube 1 or 2 ma., six minutes at a distance of 10 inches from the anticathode; or static machine with twelve revolving plates 30 inches in diameter, ten minutes at a distance of 10 inches from the anticathode) are given about every three days. The development of the desired reaction is gradual and the dosage may be regulated accordingly. Treatment is usually continued for a good many months, possibly making complete intermissions from time to time. The other method involves the administering, either at one dose or in half doses, of a sufficient amount of x-radiation to produce the necessary degree of reaction. The amount is measured by Holzknecht's chromoradiometer, and is 4 H., 5 H., or even more in certain cases. The application should not be repeated until after the development and subsidence of the reaction. This will take from three to six weeks. The Müller heavy target tube, No. 13, or the Müller water-cooled tube, No. 14, are excellent for this purpose. A localizing shield is a desirable means of protection for the operator and the patient in the treatment of most cases.

With some apparatus a primary current of 2 or 3 amperes and 12 volts is suitable for therapeutic work, while with others a primary current of from 5 to 10 amperes and from 60 to 90 volts is required. The different elements that go to produce the x-ray are so complex and mutually dependent that the only universal measure of efficiency and dosage is in the radiance itself.

The number of milliamperes actually passing through the tube furnishes a guide of considerable value, though it does not dispense with the other considerations. With a tube of medium or low vacuum 2 or 3 ma. passing through the tube usually produces about the intensity of radiance required for the normal dose. This normal dose is the strength which may be repeated every two or three days until a reaction gradually becomes established.

Gaiffe's, Snook's, or Weston's milliamperemeter, showing exactly the amount of current passing through the x-ray tube, is valuable in connection with the other factors which go to the production of the x-ray. Taken by itself it does not furnish a reliable guide.

If a large region is to be treated, the full number of units may be applied to different portions one after another. Within reasonable limits the x-raying of several different parts of the extremities on the same day does not produce an undesirable effect, but it is especially necessary to limit the application so that adjacent parts will not receive a double dose. Further details about safe and dangerous doses have been given in the article on X-ray Dermatitis.

If a transformer is used instead of an induction-coil the primary current should be turned on sufficiently to produce a current of 2 or 3 ma. through a tube with a medium or low vacuum. This form of apparatus requires no interrupter and works on an alternating circuit. The secondary current is absolutely steady, and perhaps this is the best apparatus yet devised. It is described in detail on p. 723.

X-RAY TREATMENT IN PARTICULAR DISEASES

SKIN DISEASES

The *x*-ray produces atrophy of the more highly specialized elements of the skin. This is utilized in the treatment of acne, sycosis, hypertrichosis, and excessive sweating.

Acne.—Schamberg[1] regards the *x*-ray as the most important single therapeutic measure in acne, but says that other measures are to be combined with it, especially expression of the comedones or blackheads. The latter is a measure which the present author regards as undesirable on account of scarring; freeing the sebaceous glands by friction with tar soap and warm water seem to me preferable.

The applications may be of the frequently repeated mild type or of a more severe type, such as 2 Holzknecht units repeated every couple of weeks. In either case it is necessary to produce a slight reddening of the surface, and the anticathode should be 10 inches or more from the face, so that the effect may be about equal on the whole surface exposed. The vacuum should be the lowest that will produce a brilliant radiance in the fluoroscope (resistance about 1 inch, radiometer about 2). The eyes, hair, and eyebrows should be protected, a localizing shield being very convenient. Treatment by the *x*-ray alone will effect a cure in the majority of these cases in from three to six months. Combined with high-frequency currents as a stimulating application the time is somewhat shortened and the assurance of success is greater. My own treatment is the *x*-ray and high-frequency currents combined with the following medicinal means: Internally,

℞.	Pulv. rhei	gr. ij;
	Pulv. ipecac.	gr. ¼;
	Sodii bicarb.	gr. v;
	Tr. nucis vom.	gr. v;
	Aquæ menth. pip.	ad. ʒij.—M.

This is one dose, to be taken before each meal. Externally, tar soap and warm water, used vigorously enough each night to cause redness of the skin, and followed by

℞.	Pulv. ac. salicylic.	gr. x or xv;
	Ung. zinci oxid. (vaselin base)	ad. ℥j.—M.

This is my treatment for all forms of acne, and the worst cases even of acne rosacea have been completely and permanently cured. Only the mildest *x*-ray treatment is required in this combination, and this is an especial advantage, because more severe applications of the *x*-ray may cause atrophy of the skin. The latter condition resembles the shrivelling occurring from age. I consider it unnecessary to squeeze out comedones and very undesirable to incise or curet the pustules. The scarring that can be inflicted by that sort of treatment is simply terrible.

Hypertrichosis.—Mild repeated applications of the *x*-ray, scarcely doing more than to gradually tan the skin, are entirely ineffective in dealing with this condition. To succeed it is necessary to produce a decided reaction in the skin accompanied by loss of hair. This must be repeated after about three months and perhaps more than once after that. The hair follicles can certainly be destroyed, but whether

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[1] New York Medical Journal, Feb. 23, 1907.

this can be done without producing some degree of atrophy of the skin is questionable. With careful management, this atrophy may be so slight as to be a very great improvement over the original condition in cases with almost a beard, but in cases with just a slight exaggeration of the normal downy growth x-ray treatment is not to be recommended. For x-ray treatment the vacuum should be low, the neighboring parts of the face protected, and the application may consist of 3 H. repeated once every six or eight weeks during six to twenty months; or of 2 H. every three or four weeks for six months, then stopping for two months to see whether the atrophy is going to be so marked as to make further treatment undesirable. If this is not the case treatment is recommended.

Another plan is to give a course of from six to ten treatments of such a nature as to produce a reaction from their total effect, and still have each treatment so mild and the intervals between them so long that when the reaction begins the treatments may be stopped with a knowledge that the effect will not go to an undesirable extent. This reaction should be accompanied by complete loss of hair over the exposed area, and after it has subsided the skin should be left as smooth as a baby's. The hair almost all returns after two or three months and the course of treatment has to be applied again. Three or four courses of treatment may be required during the course of a year, and are likely to be partly successful in permanently lessening the amount of hair. This method is attended by the usual risk of causing slight atrophy of the skin, and too severe a reaction must be guarded against for two reasons—one because it is painful and temporarily disfiguring, and another because it may give occasion for some legal claim against the operator. The patient ought to be told that the treatment necessarily involves the production of an inflammatory reaction, or "x-ray burn," accompanied by some redness, pain, and swelling, that it is not certain that all the hair will be permanently removed, and that there is some possibility of the skin being left somewhat thin and puckered afterward. It seems to be a matter which the operator should approach with a feeling that there is probably very little credit to be gained from treating such a case and that the wrong kind of a patient may make trouble for him. It may be undertaken at the earnest solicitation of a patient who is disfigured by a regular beard, and who understands that the result may not be complete destruction of all the hairs and that there may be some effect upon the skin.

A patient has recently been seen by the author who was treated eight years ago in another city. There had never been any redness or pain or swelling. The hair had simply fallen out, but had returned, and six months later atrophy and shriveling of the skin set in. This has recently become less and less apparent, but the chin still looks a little as if it had been the seat of a very mild but thickly distributed small-pox eruption.

Example of Application for Hypertrichosis.—The following records show a series of treatments given by the author, and which produced the right degree of reaction accompanied by the temporary falling out of all the hair of the region treated: 110-volt direct current; 12-inch induction-coil with Wehnelt interrupter; primary current 4 amperes; Friedlander tube of same size and style as the Müller No. 13, only the anticathode was connected with the positive terminal, not the accessory anode. The radiometer showed rays No. 5 Benoist. The spintremeter showed a resistance equivalent to that of a 4-inch spark. There was 1 ma. of secondary current passing through the *x*-ray tube. No series spark-gap was used. Distance from anticathode to surface of the skin 7 inches; 12 ohms' resistance in rheostat. Applications were made every other day—three were of one minute each, one of two minutes each, three of three minutes each, two of five minutes, and one of three minutes. The total exposure amounted to 7 Holzknecht units, applied in three weeks. The first effect was less rapid growth of the hair and some tanning and freckling and some tenderness. This was noted two weeks from the first application and after about 2 Holzknecht units had been applied. Four days later the hairs were brittle. After the full three weeks' applications of a total of 7 Holzknecht units there was commencing redness of the skin. The desired dose having been applied the applications were stopped and the further progress of the reaction was noted. The portion of the face which had been treated became quite a fiery red and somewhat swollen and quite painful. This gradually changed to a darker red or almost a brown color. There was desquamation of the epidermis and complete falling out of the hair, but without any ulceration. The face had to be treated in several different sections, each part in succession receiving the amount of exposure specified above, while the rest of the face was protected by sheet lead. Besides the atrophy of the skin, there may develop a dilatation of the superficial blood-vessels, such as seen upon the noses of chronic alcoholic subjects. *X*-ray treatment, then, is indicated only in severe cases where the resulting slight changes in the skin amount to nothing in comparison to the relief experienced from the removal of the original disfigurement. The more experienced the operator, the better within certain limits will he be able to regulate the changes produced in the skin.

The use of an *aluminum filter*, 1 mm. thick, and the application of single doses of 1 Sabouraud (5½ H.), or a little less, is apt to cause falling out of the hair without inflammatory reaction; it may have to be repeated several times to secure any permanent removal.

Favus.—In this disease, when it affects the scalp, the *x*-ray is probably the best means of treatment. The object should be, by one or two vigorous applications, or by a series of frequently repeated milder ones, to produce complete temporary loss of hair. After this has been produced it is easy enough to eliminate the fungus by suitable medicaments, but this is not the case if any hairs have been left. The scalp should be exposed in four different sections (frontal, occipital, temporal, and parietal) and the anticathode should be far enough away (about 10 inches) to secure uniformity of action. Sheets of *x*-ray metal form the only satisfactory protection while each particular portion is exposed.

If one full dose is given it should be of 4 or 5 H. (Holzknecht units), and it should be repeated after three or four weeks over any portion which has not become depilated. This treatment produces a very decided reaction, which is most severe in the regions already inflamed by the disease. The hair falls out and there is considerable desquamation. The hair begins to grow again six weeks after it has fallen out, but, of course, the follicles which have been destroyed by the favus ulceration are not regenerated. The application must not be too severe or the hair follicles will be destroyed by the *x*-ray and the part remain permanently bald. This is Holzknecht's own method, but Freund, of Vienna, and most operators in America secure the same reaction in the course of three weeks by repeated milder applications. A medium degree of vacuum should be used.

Alopecia areata is treated in the same way as favus and with fairly good results. The application need not extend more than ½ inch beyond the margin of the area affected, and must be somewhat less vigorous for the beard than for the scalp. Neither in this disease, in favus, nor in any other is it likely that the beneficial effect is due to bactericide action. In favus it is good almost solely as a depilatory, and in alopecia areata it has a slight stimulating effect upon the hair follicles. This last is shown even when no visible reaction has been produced. As the result of *x*-ray depilation for alopecia areata is somewhat uncertain it may be wise to follow Freund's suggestion and try the effect upon one small area before treating all the regions affected. In no case should repeated severe reactions be used that would destroy the hair follicles entirely.

Sycosis.—*X*-ray treatment gives excellent results, the technic being the same as for favus of the face. It is one of the diseases in which the *x*-ray may be regarded as a specific.

Psoriasis.—One full dose of 2 H. for the face or 3½ H. for the body suffices to cause the disappearance of the patches over the area exposed. The hair should be protected by *x*-ray metal. No inflammatory reaction should be sought. Recurrence is as liable to take place as after any other treatment. Or smaller doses may be given, and repeated every day at first, and later every other day, until the appearance of the slightest possible reaction. The vacuum of the tube should be medium or low.

The author's experience indicates that the diseased area is much more susceptible to the *x*-ray than the surrounding skin, and also that a second course of treatment finds the diseased areas with an increased susceptibility. The point of the elbow where the disease is often present is particularly slow to heal after a severe dermatitis. Smaller doses than usual should be used in recurrent cases of psoriasis.

The way in which the patches disappear is quite remarkable. There is no doubt about this being due to the application of the *x*-ray, because areas which receive a sufficient dose clean up completely, while those insufficiently treated do not show complete improvement. The center of a large patch may become perfectly clean if the tube is close to the surface and is kept in one position, while the edges are but slightly improved. The distance in this case from the anticathode to the edges of the psoriatic patch may be considerably greater than from the anticathode to the middle of the patch. As the intensity diminishes with the square of the distance the tube must either be at a considerable distance, so as to reduce the difference in the relative distances, or the tube must be changed from one position to another during the exposure. A greater distance requires a much longer exposure.

If success requires equal exposure of all parts of a single patch it will be readily seen that a number of patches on different aspects of a limb must be treated individually.

The application should be limited to the areas of disease and a small zone of surrounding skin. This is not to prevent undue action on the neighboring skin, for, as already mentioned, the dose required to affect the diseased area is smaller than that required to affect the sound skin. So many regions of the body are affected that application to all of them with a bare *x*-ray tube might produce some undesirable effects—baldness, sterility, or constitutional disturbance. Such a shield as the Ripperger is useful. It is a box made of opaque material completely surrounding the x-ray tube except for a 4-inch opening. This opening is directed toward the part to be treated. Smaller diaphragms may be used, or a piece of sheet lead may be fastened to the surface of the body with an opening of the right size and shape to expose the psoriatic patch to the action of the x-ray.

Lipoma.—This disease, especially Dercum's disease, has been treated by the applications of x-rays No. 5 to No. 7 Benoist. Nogier,[1] who reports such a case, found that the fatty tumor would diminish in size but not entirely disappear. The pain of lipomatosa dolorosa is quickly relieved by the same treatment. The disease takes a long course of x-ray treatment, and there does not seem to be any great probability of cure. Massive doses of 4 or 5 H., repeated every two or three weeks, have been used in the cases thus far reported.

Keloid.—The successful treatment of the disease by the x-ray has been reported by many different operators, and it can no longer be considered *sub judice*. Some degree of reaction should be excited, but no ulceration. Rays No. 5 and a quantity of about 6 H. may be applied once in five or six weeks, or milder doses, amounting to the same total, in about three weeks, and then followed by an intermission of three weeks.

The case shown in Fig. 742 of keloid of the lobe of the ear was given a number of x-ray applications at St. Bartholomew's Clinic with commencing benefit, but abandoned treatment before it was complete. It was more of a tumor than most cases of keloid. They are often more like hypertrophied scar-tissue and are then more quickly amenable to treatment. It takes from three to six months in any case, and there are so far no observations to show whether it removes the tendency to the development of this abnormal tissue in new places. It is a treatment which is to be very strongly recommended in cases of larger extent, where electrolysis would be painful and tedious. The x-ray is not the only successful treatment for keloid and perhaps not the best one. Treatment by thiosinamin is to be considered.

Fig. 742.—Keloid of the ear treated by the x-ray.

Thiosinamin in the Treatment of Keloid.—This method of treatment was introduced by the author in 1894,[2] and consists in the internal administration or the hypodermic use of the drug in question. Thiosinamin is a substance which produces a very marked temporary leukocytosis and has a tendency to cause the absorption of fibrous or cicatricial tissue. It is useful in keloid, in which it not only causes the absorption of the growth but also removes the constitutional tendency to it.

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[1] Arch. d'Elec. Med. Exp. and Clin., 13, 363, May 25, 1905.
[2] New York Medical Journal, 1894.

The importance of the latter feature is very great. These cases develop a larger keloid in the scar if the original growth is excised. They develop one in each needle-puncture if hypodermic treatment is adopted. A keloid developed in the scar from too intense phototherapy in a case reported by Belot.

A case treated by the author was one of a college student who developed keloid in a vaccination scar. After one excision this formed a large mass with numerous prolongations, disfiguring and greatly disabling the arm. Thiosinamin was at first used by hypodermic injection near the growth, but as new keloids soon developed in each needle puncture the method of administration by capsules to be swallowed was adopted. Treatment had to be continued for about a year, but resulted in a complete cure of the growth and of the tendency to the formation of others.

Whether the *x*-ray alone will cure the tendency to keloid is a question not yet settled.

Cases of multiple keloid have been reported by Sievers[1] which were cured by the *x*-ray without any other medication and had shown no recurrence in two years.

Hyperidrosis.—This disease has been treated by the *x*-ray and a successful technic described by Leopold Freund.[2]

My own technic is illustrated in the following case of most extraordinary hyperidrosis palmaris. The patient, a physician twenty-seven years old, had always suffered from such sweating of the palmar surface of the hand and fingers that sixty seconds after wiping his hands on a towel the unnatural secretion would fall from his finger-tips in great drops.

The treatment consisted in a single massive dose for each hand of unfiltered *x*-rays about No. 7 Benoist penetration and $\frac{1}{60}$ Tousey intensity and about 10 Holzknecht units of quantity. This dose was applied from a tungsten anticathode 7-inch bulb excited by a 12-inch induction-coil with a wheel mechanical interrupter. The primary current was 5 to 6 amperes, the secondary 1 to $1\frac{2}{5}$ ma.; the distance from the anticathode to the skin $6\frac{1}{2}$ inches and the time of exposure twenty-eight minutes. This was much more than a Sabouraud and Noiré erythema dose of $5\frac{1}{2}$ H., and was made possible by the toughness of the skin involved and preliminary tests of its sensitiveness in this particular case.

The result was redness and swelling coming on after a period of incubation. Dry desquamation, except in one small area where there was an actual blister. The skin was left smooth and dry, and when seen a few months later the palmar surfaces were as dry as a bone.

This radiance required an exposure of sixty minutes upon a Sabouraud barium platinocyanid pastille at $6\frac{1}{2}$ inches from the anticathode to change it to Tint B. Sixty minutes at 13 inches (twice as far as the pastille) would, therefore, have applied a Sabouraud dose to the skin and one-quarter that time or fifteen minutes would have been a Sabouraud dose at $6\frac{1}{2}$ inches, the distance at which the application was actually made to the skin.

Eczema.—This disease is very amenable to *x*-ray treatment, and, according to Leonard, the lowest practicable degree of penetration produces the best results. The *x*-ray tube may show the blue cathode

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[1] Med. Gesellsch. zu. Leipzig, January, 1907.

[2] Gesellschaft der Aerzte in Wien, Sitzung von, Jan. 29, 1909.

stream and the radiometer may indicate a penetration of only No. 1 Benoist. Practically the whole radiation is arrested by the skin—absorbed by it. A tube in this condition converts a very small fraction of the electric power passing through it into Röntgen radiance. The latter is not very powerful, and rather long exposures are required, and the tube may be very near the skin. It is difficult to define the dosage exactly, and probably the safest way, until one has experience as a guide, is to give practically the same exposures that would be given at the same distance with a medium degree of vacuum. Other operators use a medium vacuum. No screen for soft rays is used. If a single dose instead of divided doses is given it should amount to 3 or 4 H.; the limbs will require separate exposures.

Warts and Moles.—These may be treated by frequent exposure to moderate doses or a single exposure to a very heavy dose (8 H.). In the latter case it is very important to protect the sound skin. Some of these show a tendency to develop into epithelioma, and in such cases it seems probable that the slower milder treatment is better. There is some reason to believe that a severe change in the skin from the *x*-ray produces in some cases a tendency toward malignancy.

Pruritus.—Itching of the skin, with or without anatomic change, is relieved by mild applications of the *x*-ray combined with the use of high-frequency currents from ultraviolet ray vacuum electrodes or from copper electrodes. This, however, should be combined with other appropriate treatment, such as an ointment containing resorcin, carbolic acid, alum, and ichthyol; the internal use of salophen, 10 gr. three times a day. The latter is of the greatest service in the cases which are dependent upon a uric-acid diathesis.

Nevi.—Vascular or hairy nevi or port-wine stains may be treated by the *x*-ray, but mild applications produce little or no effect. There must be a very marked reaction, although it is better to avoid ulceration. After successful treatment the skin may show slight atrophy and its color may not be absolutely normal, having somewhat of a cicatricial character. In these cases the choice of treatment lies between ignipuncture, electrolysis, excision, and the *x*-ray. Where the nevus is so small that it is possible to secure a linear cicatrix excision is best. Electrolysis is excellent for nevi of moderate size where the cosmetic effect of excision would be bad. The *x*-ray is adapted to cases of large extent and in which the disfigurement is so great that the result obtained, even though it can hardly be expected to be perfect, will be a very great improvement. In these cases a single dose of 4 H. may be given, protecting the neighboring parts, and repeating it after a month. The second dose may be the same or of slightly greater strength, depending upon the degree of reaction. The vacuum should be medium, and if repeated fractional doses are given the radiance should be rather brilliant, so as to be a little more than the standard dose on p. 1064. The degree of reaction sought is one accompanied by slight blistering, but without ulceration.

Chronic Ulcers.—The *x*-ray does not appear to have any specific effect upon an ulcer, but exposure to the *x*-ray may produce two different results. There may be a stimulation due to the charge of static electricity emanating from the *x*-ray tube and having a tendency to stimulate healing, and there is a regular cloud of atmospheric dust repelled from the *x*-ray tube, and if a raw surface is exposed to this a dangerous implantation of bacteria and other particles may take place. This last effect may be prevented by the interposition of a thin piece of cloth. Mild doses, like those on p. 1064, repeated only once a week, may be used. There are so many better applications, electric and otherwise, that the *x*-ray will hardly be chosen unless there is some special reason, such as the fear of a development of malignancy.

Syphilitic Gumma.—A case of ulceration of the side of the neck from a broken-down syphilitic gumma, which had remained open for a couple of years, was successfully treated by means of high-frequency effluves and very soft *x*-rays.[1]

Syphilitic Rhinoscleroma.—A case referred to the author as probably one of lupus, but which was subsequently thought to be of a syphilitic nature, did remarkably well under *x*-ray applications, and was promptly and completely cured when antisyphilitic medication was added (Fig. 743).

Scorbo, of Naples, has treated a syphilitic lesion of the skin by ultraviolet light and the *x*-ray.

Rhinoscleroma.—Freund[2] reports the cure of such a case by twenty-five applications of the *x*-ray. The nose was thick and indurated and the nostrils were blocked up with nodules, which also involved the hard palate and the posterior wall of the pharynx. Dittrich's bacilli had been found in the tissues.

Fig. 743.—Supposed lupus of the nose benefited by *x*-ray applications, but promptly cured by antispecific treatment.

Leukoplakia Buccalis.—Leduc[3] reports 3 cases treated by exposure of the tongue to medium soft rays at a distance of 20 cm. (8 inches) from the anticathode for two minutes at the first treatment, possibly repeated in three weeks. The leukoplakia completely and permanently disappeared without the sound part of the tongue showing any effect from the application.

Cicatricial Contractions.—These yield slowly to the influence of mild applications of the *x*-ray. Thiosinamin is also excellent in these cases, and requires to be given internally for six months or more. Its effect is more fully explained in the paragraph on keloid.

Leprosy.—This is a disease in which some of the cutaneous lesions are susceptible of improvement by *x*-ray treatment, and, according to Oudin, the *x*-ray seems to have a specific effect upon the morbid tissue without affecting the neighboring sound tissues. The application should be sufficient to produce a mild erythema, not ulceration; 5 or 6 Holzknecht units should be applied to each of the regions treated. This amount may be a single dose or divided among several sessions.

Scholtz, on the other hand, did not observe any decided benefit, clinically or microscopically, from *x*-ray applications in 2 cases of leprosy which he treated.

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[1] Laquerriere, Bulletin officiel de la Société Française d'Electrothérapie, Dec., 1905.

[2] Wiener Med. Woch., June 25, 1905, p. 1279.

[3] Arch. d'Electricité Medicale, Feb. 10, 1907.

From a study of cases of leprosy made in the hospitals of Norway it seems to the author that the x-ray may be of service in the treatment of the tubercular cutaneous and subcutaneous nodules and of the chronic ulcers which characterize the disease. The larger question, as to whether the disease itself can be cured by x-ray applications over the spine or the hematopoietic organs, must be left undecided, but when one sees case after case which has suffered from the steady advance of this terribly mutilating disease for fifty years it seems as if an effort should be made to conquer the bacillary infection or the trophoneurosis by x-ray treatment. Applied in these two directions, and with courses of treatment extending over long periods of time, but only to the extent of causing stimulation of the skin, never ulceration, it may prove the means of curing the disease. We know of nothing else in the whole Pharmacopœia which has so marked an effect upon the whole organism in therapeutic doses.

A Case of Leprosy Apparently Cured by the x-Ray.—This case is reported by Victor G. Heiser of the Leper Hospital at Manila.[1] The different lesions were exposed for ten minutes every third day to a radiance just intense enough to show the outline of the intracarpal bones clearly. An ordinary x-ray tube was used with an 18-inch induction-coil and a mercury turbine interrupter. The distance from the tube was 10 inches for the first three weeks, beginning Nov. 5, 1906, but improvement was not effected until after the distance had been reduced to 6 or 7 inches. During June, 1907, after seven months' treatment, the lesions seemed almost cured, and the lepra bacilli, which had been abundant, became difficult to demonstrate. By January, 1908, after fourteen months' treatment, the lesions were all healed, the infiltrations had disappeared, and there were no anesthetic areas. The lepra bacilli could be detected only in scrapings from the septum of the nose. During the months of June and July, 1908, it was impossible to find lepra bacilli in any part of the body. At the last observation, August 1, 1908, after nearly two years' treatment, the patient was apparently cured.

Scleroderma.—Encouraging results have been reported from applications of 6 or 8 Holzknecht units of No. 5 rays made every three weeks. The sclerotic patches are apparently less sensitive to the x-ray than normal skin; for these rather large doses do not excite an inflammatory reaction. No complete cures have been reported.

Chilblains.—The redness and pain are relieved even in severe recurrent cases by the x-ray and high-frequency currents. Ichthyol ointment is excellent and so is white lead. The author has had very great success in treating these cases by immersing the feet in mackerel brine, as hot as it can be borne, for about fifteen minutes. This may be repeated in two or three days, and these two applications will probably suffice for the whole winter and there may never be a recurrence.

Tinea Capitis or Ringworm of the Scalp.—The discovery that the x-ray is the most effective means of treating this disease is due largely to Sabouraud and Noiré, and their names have become associated also with a convenient method of measuring the dosage of x-ray required for the treatment of this disease. Their method is to apply rays of a medium or low degree of vacuum (No. 4 or 5 Benoist), with a sufficient exposure to produce complete falling of the hair without inflammatory

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[1] New York Medical Record, Oct. 31, 1908.

reaction and without ulceration. Their method of measurement is based upon the change in color undergone by barium platinocyanid when exposed to the *x*-ray. A little tablet coated with this chemical, which is the same that is used in fluoroscopes, is placed 8 cm. from the anticathode, while the surface to be treated is at a distance of 15 cm. When it has turned to a standard color, so as to exactly match one of the brownish-yellow tablets supplied with the apparatus, we know that a certain quantity of *x*-ray has been applied. One of the test tablets indicates an exposure which is about the proper dose for ringworm. This indicates the application of 5½ H., which is the largest dose that can be applied without producing radiodermatitis. The quantity to be applied varies a little. Only 4 H. is required for a child, and 5 H. is the average dose for application to the hairy scalp in adults. The Sabouraud and Noiré pastils form a most convenient means of measuring the dose. Haret's little device holds the pastil attached to the *x*-ray tube at just the correct distance from the anticathode. Ordinary light affects the barium platinocyanid, so the pastil is kept covered by black paper, except occasionally, when it is turned back for comparison with the test object, which also is held in position. It is not necessary to turn off the current while making this comparison. Holzknecht's chromoradiometer, depending on the change in color of another chemic compound, may be used. The author's own method is based upon the intensity of the *x*-radiance, which can be measured before the exposure is begun, enabling one to determine beforehand just how many minutes the *x*-ray is to be applied. It is described on another page and is excellent for many purposes, but presents too great a personal equation for general use in these particular cases.

The treatment of these cases without any exact means of measuring the amount of *x*-ray applied is to be most strongly deprecated. Before the introduction of the Sabouraud and Noiré method of applying an exactly measured dose at once or in two parts, separated by a day or two, the best radiologist had most uncertain results in these cases.

An example of suitable technic would be the employment of a 12-inch induction-coil with great self-induction, a Wehnelt interrupter, 110-volt direct current, about 4 amperes of primary current, Müller No. 13 tube, resistance (parallel spark) 2 inches, radiometer No. 5 Benoist, secondary current 1 ma., no spark-gap, intensity No. 6 Tousey, 8 ohms' resistance in rheostat, 1 ma. of secondary current. At a distance of 15 cm. from the anticathode to the skin in one of the author's ex-

Fig. 744.—Ringworm of the scalp (tinea capitis) cured by *x*-ray.

posures twenty minutes amounted to about 4 Holzknecht units, and was suitable for the total dose, not to be repeated, in a case of tinea capitis in a child three years old (Fig. 744). The treatment was successful.

All portions of the scalp that are affected must be treated, and all must receive an equal application of the *x*-ray. The strength of the rays and hence the quantity absorbed in a given time varies inversely as the square of the distance from the anticathode. The convex shape of the head would result in the part directed toward the *x*-ray tube being very much more affected than the other parts if a single exposure were made in a fixed position. It is necessary to turn first one part and then another toward the tube, protecting other parts by sheet-lead while one part is being treated. Practically the whole scalp may be treated in four sections—frontal, occiptal, and right and left parietal.

It is unwise to attempt to make this subdivision of the exposure by means of a diaphragm which regulates the distribution of the rays from the tube. Such an arrangement is excellent for treating a single area, but it would be very difficult to prevent some contiguous portions of two neighboring areas from receiving a double exposure, and other parts would perhaps not receive any. Using the sheet-lead, a portion on one side of a perfectly straight line may be treated during the first part of the exposure and the portion on the other side of that line during the second part of the exposure.

Each successive part that is exposed is to receive an exposure of about 4 Holzknecht units.

Mode of Action of the x-Ray in Tinea Capitis.—The disease appears to be due to an infection by microörganisms which are limited to the horny layer of epidermis in the hair follicles. In this position the infection is difficult or impossible to eradicate by any ordinary chemic or mechanical means. The hairs break off if one tries to pull them out, as in favus, where epilation will often effect a cure, and the microörganisms are beyond the reach of lotions or ointments or even gaseous substances.

The *x*-ray kills the horny layer of epithelium in the hair follicle, and this layer with the contained germs falls out with the hair.

The new hair grows out free from infection.

The sound hairs of the area exposed to the *x*-ray fall out just the same as the diseased ones and are also replaced by new hairs.

The Danger of Reinfection.—The disease is a most contagious one, and one portion of the scalp may be inoculated from any other part. The exfoliated hairs carry perfectly live and active germs (tricophyti), and must be prevented from starting new areas of disease. Sabouraud makes daily applications of flowers of sulphur to the diseased area from the tenth to the thirtieth day after irradiation.

Such an application as

℞. Sulphur precip. }
Sp. vini rect. } ....āā ʒss;
Aquæ ....ad. ℥iv.—M.
Sig.—Shake before using as a lotion.

is also effective. Or the scalp may be rubbed daily with

℞. Tr. iodi.. ʒiss;
Sp. vini rectif.................................ad. ℥j.—M.
Sig.—Lotion.

Ringworm of Other Regions than the Scalp.—The same disease affecting the beard should receive milder applications of the x-ray because of the greater susceptibility of the face to the x-ray dermatitis. It will probably be found unwise to make an application severe enough to produce complete depilation on any part of the face.

Mycosis Fungoides.—The x-ray treatment yields good results in this condition. The application should be thorough, 3 to 5 H. at a single application, protecting the surrounding parts, or repeated applications of a strength that the operator knows will gradually produce a decided reaction.

Lupus.—The x-ray treatment of lupus is practically certain of considerable success. The time required for each treatment is only a few minutes and the number of treatments is from five to fifty. In both these particulars it possesses advantages over the Finsen treatment. Some cases treated by the best and most expensive Finsen apparatus require four hundred and seventy treatments. Whether there is an equal prospect of success with the two methods has not been definitely settled, but in most cases the preference lies with the x-ray, at least for a fair trial, or as a preparation for Finsen treatment. A great many cases have been reported, and many have been cured, though perhaps the majority cannot be entirely cured by the x-ray alone. The method produces a better cosmetic effect than curetage or cauterization and is free from pain, but it requires about as long a course of treatment as any other method.

The treatment by mild applications, repeated every two or three days until a slight reaction has been produced, and by then maintaining this degree of reaction throughout, is the one which is perhaps the safest. For details of the method see page 1052. The other method involves the application of 3 to 5 H. once a month for five or ten months and is also good. In lupus vulgaris the change produced by the x-ray is one of degeneration of the lupus nodules followed by inflammatory changes in the neighoring tissue, and if severe applications are made the whole diseased area may slough out; 7 or 8 Holzknecht units at a single session, or as the total of the applications made in a single week, will produce sloughing, but this is seldom desirable. The ulcer is painful and takes perhaps many months to heal. Milder applications without an intense reaction produce a sort of sclerosis, followed by absorption of the lupoid tissue with disappearance of the bacilli.

It is important to note that the effect upon the disease is not due to the bactericide action of the x-ray. The latter is so weak that it would require tremendous overdoses to directly influence the bacilli. The effect is produced directly upon the tissue-cells, and they are in some way enabled to dispose of the bacilli.

Whether strong or weak applications are made, the x-ray certainly has a curative effect, and the milder treatment carefully conducted is less apt to cause a painful ulceration at any stage of the case. Of course, fresh lupus nodules may come to the surface and prolong the treatment.

In lupus erythematosus there is not the same reason to expect ulceration, and so either the gradual method or that by massive doses of 3 or 4 H., repeated every month or six weeks, may be employed. The vacuum in the tube used for the milder frequent applications in all forms of lupus should be medium, 3 or 4 inches spark resistance and 5 to 7 radiometer, but for the heavier doses the vacuum should be low, 1 or 2 inches spark resistance and 2 or 3 radiometer. It will often be found advantageous to combine occasional curetage of certain nodules with the *x*-ray treatment. After the disease germ appears to have been eliminated it will often happen that a complete cure will be promoted by Finsen treatment, and will not take place under the *x*-ray alone even if continued for a long time.

Belot[1] analyzes the treatment of different forms of lupus as follows: "While certain cases of lupus of the extremities are benefited by curetage, any extensive case of lupus, whether ulcerated or not, ought to be treated by the *x*-ray; this treatment is more rapid and effective. Rebellious points are to be treated by phototherapy, but it may be that the *x*-ray produces changes in the tissues which interfere with the beneficial action of the arc light. Phototherapy properly applied gives excellent results in small localized lupus."

A few of the authors to whom our knowledge of the curative effect of the *x*-ray in lupus is due are Jutassy, Schiff, Freund, Scholtz, Campbell, Hyde, Montgomery, Ormsby, Kummel, Gocht, Albers Schönberg, Gassmann, Neisser, Lee, Pfahler, Uhlmann, Pusey, Kienböck, Holzknecht, Béclère, Williams, and Belot.


Fig. 745.—Lupus (or epithelioma) of the face cured by *x*-ray.

A patient with this disease was referred to the author by Dr. Jarman. She was sixty-seven years old, and had had a patch of lupus vulgaris upon the cheek for about a year. Her father had a similar trouble, which had caused the entire ala of the nose to ulcerate away. The technic for each treatment was as follows: No. 13 Müller tube, radiometer No. 2½ Benoist; resistance 2½ inches; 8-inch induction-coil; Caldwell interrupter; 110-volt direct current; 4 amperes primary current; 1 ma. secondary current; anticathode and accessory anode connected; distance, 8 inches; intensity, No. 5 Tousey; 8 ohms' resistance in rheostat. Five-minute exposure equaled 1 Holzknecht unit. The exposures were of two minutes' duration and thirty-five treatments were given in a period of two and a half months. The total exposure during this time amounted to about 14 Holzknecht units. There was at no time anything more than the slightest degree of redness and itching. A complete cure was effected and there has been no recurrence in three years. There is no scar upon the face. It should be added that the diagnosis was made from the clinical appearance and history, not from microscopic examination. It is, therefore, not absolutely certain that the disease was lupus and not epithelioma.

Absence of Effect Upon Hydatid Cysts.—There is no apparent reason why the *x*-ray should succeed in destroying the parasites which cause this disease, and Dévé has found from experiments on this disease in rabbits that this supposition is correct.

Röntgenotherapy for Pyorrhea Alveolaris is described on page 595.

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[1] Le Radium, Sept. 15, 1905, p. 300.

X-RAY THERAPY IN TUBERCULOSIS

Experiments by Bergonié and Tissier[1] showed that the *x*-ray had no effect upon the tubercle bacilli in a culture, and that it had no marked effect upon the lesions of experimental tuberculosis. They concluded that the *x*-ray had a doubtful influence upon clinical surgical tuberculosis and none upon phthisis.

Mühsam, at the same date,[2] found that the *x*-ray did not produce tuberculosis in guinea-pigs, and that it only slightly attenuated the local manifestations of this disease if the animal was inoculated with it. The *x*-ray did not completely cure tuberculosis in guinea-pigs.

Rodet and Bertin-Sans, about the same time,[3] found that the *x*-ray had an unfavorable effect upon nutrition, and that in cases of tuberculosis the *x*-ray moderated the infection in the lymphatic glands, but somewhat favored generalization in the viscera. Their verdict was that no benefit resulted from the treatment.

Rieder, a little later,[4] came to the conclusion from his observations that, while the *x*-ray appeared to attenuate or kill different disease germs in glass test-tubes, the rays had no such effect upon infectious processes in animals inoculated with different pathogenic germs. His results at that time seemed to show that local tubercular processes were favorably influenced, and that in some cases generalization of the disease was antagonized. The animals experimented upon died, however, doubtless from organic disorders produced by the irradiation. He reported negative results in human tuberculosis.

Since that time increased knowledge as to the dosage of the *x*-ray has led to improved results, and the *x*-ray has become a most valuable therapeutic agent, especially for localized tubercular lesions. Bergonié[5] finds that, with modern technic, the *x*-ray has a clearly favorable effect upon non-suppurative tubercular glands. According to this observer all the tumefied glands which are treated become smaller, but rarely completely disappear. The disease, as it affects the joints, the larynx, the peritoneum, the lungs, the skin, and other parts, has been very favorably influenced by the *x*-ray. We know that tuberculosis, like many other infectious diseases, is often recovered from if the local lesion is controlled and if the general health is maintained, and the local lesions are often of a character or situation to make them difficult to directly influence by any other measures than the *x*-ray.

The effect of the *x*-ray is not directly upon the tubercle bacilli, but upon the lowly organized tissue with rapidly developing cells characteristic of this disease. The effect of the *x*-ray is greatly added to by combining with it the use of high-frequency currents. The latter may be applied from ultraviolet ray vacuum electrodes, or by placing the patient between two Oudin or Guilleminot resonators in such a way that the effluve or perhaps only the invisible discharge is intercepted by the patient's body. The ozonizing effect of high-frequency currents, applied in either of these ways, is of great therapeutic value, acting by stimulating the tissue cells and increasing metabolism as well as by circulatory stimulation.

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[1] Congress of Tuberculosis, 76, Paris, 1898.

[2] Münch. Med. Woch., 24, 715, Nov. 10, 1898.

[3] Arch. d'Electricité Medicale, 413, 1898.

[4] Münch. Med. Woch., June 18, 1899.

[5] C. R. Acad. des Sciences, 140, 889, Paris, March 27, 1905.

Röntgen Therapy in Cutaneous Tuberculosis.—Moderate exposures repeated two or three times a week have a curative effect upon the warty or nodular type of the disease and upon the ulcers and fistulæ which accompany another type. A suitable exposure for each application is one and a half minutes, at a distance of 12 inches from the anticathode, with a penetration of No. 4 Benoist and an intensity of $\frac{1}{80}$ Tousey. Each application amounts to about $\frac{1}{2}$ Holzknecht unit, and the application may be kept up for three or four weeks if necessary and then intermitted.

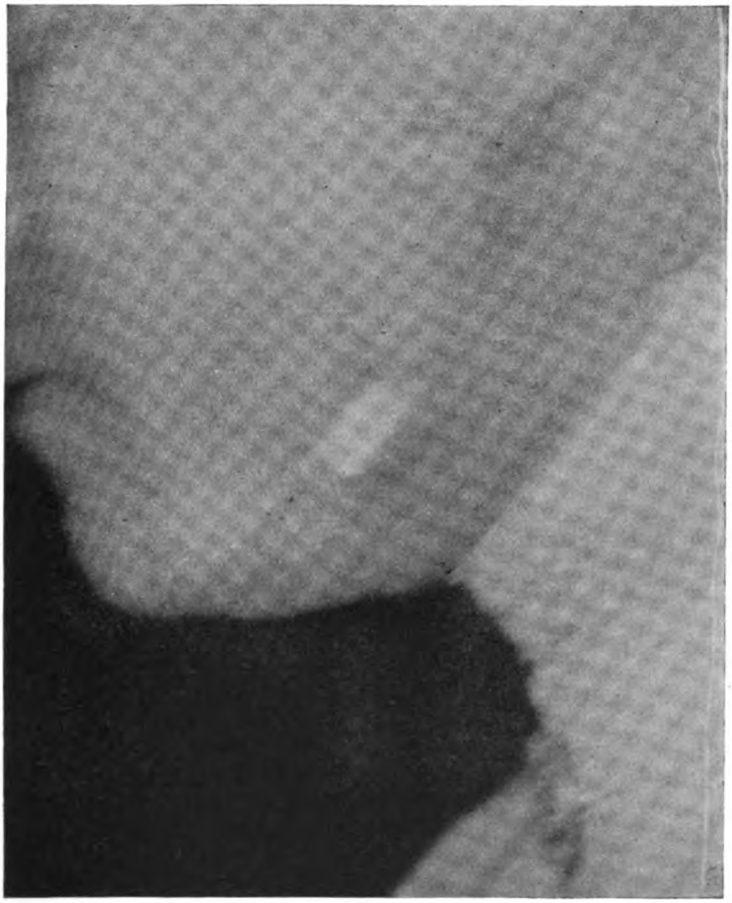

Fig. 746.—Tubercular sinus of face originating in a sebaceous cyst; cured by *x*-ray treatment.

Tubercular Adenitis.—Chronic tubercular glands with periadenitis, treated by Röntgen ray, may become smaller and change to fibrous nodules which do not entirely disappear. Acute tubercular glands, and those already having a tendency to soften, may be caused to undergo cheesy degeneration. The author has observed excellent results from *x*-ray treatment in suppurative tubercular glands of the neck already opened spontaneously or by the surgeon's knife. He has successfully treated a case of chronic sinus of the back following an operation for tubercular osteitis or tubercular arthritis of the spine by exposure to the *x*-ray. The *x*-rays were of a quality of about No. 5 Benoist and an intensity of about No. 5 Tousey. The anticathode was about 10 inches from the surface of the body, and the applications were for about five minutes every other day until the skin became slightly reddened. Each application amounted to about 1 Holzknecht unit. Röntgenotherapy results in better cicatrices as well as more rapid healing in cases of tuberculous abscess and sinus.

Tubercular Lymphatic Glands of the Neck.—These are readily amenable to treatment by a radiance of a penetration of No. 5 or 6 Benoist. Short applications of about a minute and a half, at a distance of about 9 inches from the anticathode, may be made three times a week until some reaction appears. Then the treatment should be intermitted. Each application, made according to this plan, should be calculated to be a little less than 1 Holzknecht unit. Another plan is to make massive applications of 4 or 5 H. at a single session, or as the total of two or more sessions, occurring within the course of two or three days. No more applications should be made for two or three weeks, but it may then be repeated. It is quite important to limit the application by a shield or by covering all other parts of the patient with sheet lead. Baldness and sterility and any possible toxemia are thus avoided.

The results are that the glandular mass shrivels and certain glands cease to be palpable, while others remain as innocuous small fibrous nodules. Leonard has found that the lymphatic vessels are converted into fibrous cords. Cases treated by the author make this treatment of tubercular glands of the neck seem preferable to surgical extirpation, because this treatment leaves no scar and because it permanently closes certain lymphatic channels and hence tends to protect the patient from general infection.

Tuberculosis of the Mediastinal Lymphatic Glands.—Disease in this location is also amenable to treatment and the radiance required is one which will give a good fluoroscopic image of the chest, or will produce a good radiograph of the chest with an exposure of five minutes or less. The *x*-ray may, therefore, have an intensity of No. 10 Tousey and a penetration of No. 6 Benoist. The anticathode should be 13 inches from the surface of the body, and an exposure of three minutes may be given twice a week, with intermissions on the development of some redness of the skin. A screen for soft rays, made by interposing a piece of sole leather, or a single layer of tin-foil, or a sheet of aluminum $\frac{1}{50}$ inch thick between the *x*-ray tube and the surface of the body, will tend to prevent dermatitis while permitting the passage of the more penetrating rays, which alone could reach the seat of disease anyway and which are less irritating to the skin. The nearest skin surface should receive about 2 Holzknecht units a week, and a distance of 13 inches is great enough not to make too great a disproportion between the distance to the skin and that to the seat of disease. If the tube were so near that the distance from the anticathode to the cutaneous surface were only half the distance to the deep-seated lesion, the divergence of the rays would result in the skin being exposed to a radiance four times as intense as that which reached the mediastinal glands. Under such conditions it would be difficult to produce any therapeutic effect upon the mediastinal glands without a bad effect upon the skin.

Massive doses are available here as elsewhere, but probably are less desirable than mild frequently repeated ones.

The results of this treatment are variable, but it is certainly capable of great benefit in certain cases.

Associated as this disease is so apt to be with pulmonary tuberculosis, it will often be advantageous to combine the *x*-ray and high-frequency currents in its treatment.

Tubercular Lymphatic Glands in Other Regions.—These are treated in the same way and with due regard to their superficial or deep situation. The applications should be localized.

Réné Desplats has made blood examinations in patients with tubercular adenitis treated by the *x*-ray and finds a reaction similar to that which occurs in leukemia under this treatment.[1]

Tubercular Peritonitis.—Röntgen ray treatment has proved beneficial in a case of tubercular peritonitis in which an exploratory laparotomy had been done and the fluid evacuated and the diagnosis confirmed by the microscope. Repeated tapping was required until *x*-ray applications were made. A lasting cure was obtained in this way, a slight recurrence disappearing at once under *x*-ray treatment.

The application in such cases should be over the whole front of the abdomen, of a penetration of about No. 6 Benoist, and if the intensity is $\frac{1}{60}$ Tousey, the anticathode being at a distance of 10 inches from the skin, the exposure should be six minutes (equivalent to 1 H.). This amount of radiation is applied three times a week. The soft rays which might cause dermatitis may be arrested by an aluminum or leather screen.

Tuberculosis of the Kidney.—This is a disease in which the *x*-ray and high-frequency currents did good in one of the author's cases. The *x*-ray seemed to act by breaking down exudative masses and the high-frequency currents seemed to stimulate the elimination of enormous collections of pus. The local condition was improved, but general infection had probably already taken place and the patient died. The applications should be limited to the lumbar region on the affected side. The anticathode should be 13 inches from the surface of the body and the radiance should have a penetration of No. 6 Benoist and an intensity of about No. 7 Tousey. A screen for soft rays will protect the skin to a certain extent. The exposures should be given two or three times a week, and be of such a length that redness will develop in three weeks and change to bronzing in six weeks, without ever having any soreness. An application amounting to 1 H. at the surface of the body twice a week is about correct.

Massive doses of 4 or 5 H., applied once every four or five weeks, are permissible, but are probably somewhat less desirable. A mild continuous effect seems usually better for tubercular processes, and this is a region where the toxemic effect, which sometimes immediately follows any *x*-radiation, might be serious if the dose were a large one.

The *x*-Ray Treatment of Pulmonary Tuberculosis.—A certain number of patients have recovered from tuberculosis of the lungs under treatment by the *x*-ray and high-frequency currents and others under high-frequency currents alone. These recoveries have been characterized by the disappearance of all the symptoms of the disease, including the bacilli in the sputum, and by the radiographic findings characteristic of cured pulmonary tuberculosis.

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[1] Le Radium, p. 300, Sept. 15, 1905.

Other cases have shown considerable improvement under *x*-ray treatment alone, and these cases have been mostly those in which the applications have been severe enough to excite a cutaneous reaction with a possible counterirritant effect.

The best opinion at the present time seems to be that the *x*-ray has little if any permanently curative effect in pulmonary tuberculosis.

If it is used either alone or in combination with high-frequency currents the technic is the same as for tubercular mediastinal glands, and mild frequently repeated doses are to be given with the production of a slight reaction upon the skin.

Tuberculosis of Bones and Joints.—This localized form of disease is certainly benefited by the *x*-ray and some cases are cured. A chronic sinus of the back from an old operated tubercular osteitis of the lower dorsal vertebræ in one of the author's cases healed after a few applications of the *x*-ray and of high-frequency currents from ultraviolet ray vacuum electrodes. Tubercular rheumatism of the wrist has been cured by *x*-ray applications, and the pain, edema, and stiffness removed (reported by Reboul), and Béclère has reported a case of spina ventosa, tubercular osteitis of a finger with fistulæ, entirely cured by the *x*-ray.

It is to be recommended at the different stages of bone or joint tuberculosis, when an operation does not seem to be indicated or when it has not proved completely successful and repetition of the operation seems undesirable.

The *x*-ray should generally be applied from several different directions, exposing only a small area of skin at a time, so as to secure an effect upon the deep tissue without much on the skin. The choice lies between mild, frequently repeated applications, continued until there is slight cutaneous reaction, and massive doses, applied at one or two sessions. The penetration should be No. 6 Benoist and the intensity at least No. 6 Tousey for the wrist, at a distance of 10 inches from the anticathode, and No. 10 Tousey for the hip or spine, at a distance of 13 inches.

The mild frequent applications would require an exposure of three minutes two or three times a week, and the massive doses would require twenty or thirty minutes' exposure at a single session, or as the total exposure, during the course of two or three days. The author's preference is for frequent mild applications. No severe reaction is to be sought, and the use of a screen for soft rays may be found desirable.

Roederer,[1] who has collected the published reports upon the treatment of tubercular joints and other local tubercular lesions, finds no evidence that *x*-ray treatment tends to a general dissemination of the disease. My own experience agrees with this conclusion.

Spina ventosa is very favorably influenced, while the *x*-ray does not seem to accomplish much in Pott's disease or tuberculosis of the hip.

ARTHRITIS DEFORMANS

Anders, Daland, and Pfahler[2] report excellent results from the application of the *x*-ray in arthritis deformans. This treatment should be combined with other measures appropriate to the individual cases.

The Author's Experience with the *x*-Ray in a Variety of Rheumatic Affections.—The *x*-ray applications have a decided alterative effect in this whole class of cases and are a valuable adjunct to treatment

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[1] Thèse de Paris, 1906.

[2] Jour. Am. Med. Assoc., abstract in New York Med. Jour., May 26, 1906.

by high-frequency currents. The latter are applied by vacuum electrodes. A case without bony changes discoverable in the radiograph usually yields readily to the combined treatment. Bony changes, however, do not appear to be cured, though the greatest benefit may be secured in the way of arresting the progress of the disease. Illustrative cases are mentioned on p. 579.

TRACHOMA

The results of x-ray therapy in this disease have not been exactly the same in the hands of different operators. Vassioutinsky[1] reports 7 cases in which the x-ray certainly had a marked influence upon the morbid processes, especially the infiltration. The pannus yielded slowly. He did not secure any complete cures, no matter how long or how frequent the exposures were. This tissue seems to present but a slight tendency to cicatrization. The applications were absolutely painless and produced no harmful secondary effects upon the eye. He thought the x-ray would give favorable results where other methods have failed.

Newcomet has had better success in entirely curing cases.

A difference in the results of Röntgenotherapy may be due to differences in technic, and, generally speaking, it is desirable to know what the results of treatment with average apparatus and technic is likely to be.

The exposures must be calculated with special reference to the avoidance of injury to the eye. In some cases little metal or enamel shields Fig. 736, p. 1038) may be placed over the eyeball under the eyelids. A drop of cocain solution enables the eye to tolerate this. The eye is then entirely protected, and as much x-radiance may be applied to the lids as is required. It is not necessary to evert the eyelids in order to secure an effect upon the mucous surface.

Frequently repeated mild doses are desirable. The penetration should be about No. 4 Benoist, the intensity about No. 5 Tousey, and the distance about 9 inches. Exposures of two minutes three times a week amount to about 4 H. in three weeks, and this is about the proper amount to apply. The treatment may be resumed, if necessary, after an interval of a couple of weeks.

The results of x-ray treatment of trachoma while very good are not thought to be quite so good as those from treatment with radium.

RADIOTHERAPY IN SYRINGOMYELIA

Successful results have been reported by Beaujard and L'Hermitte,[2] Delherm,[3] and Grameque.[4] The applications of the x-ray are made over the affected part of the spine as indicated by the location of the principal symptoms and are of a degree of penetration equal to No. 8 Benoist. The tube should be at a distance of 10 inches, measured from the anticathode to the surface of the body. Applications of 2 Holzknecht units may be given about every six days until the development of a cutaneous reaction and then reduced in strength. It is too early, and there

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[1] Roussky Vratch, 12, Jan. 8, 1905.
[2] Semaine Medicale, April 27, 1907.
[3] Bulletin Officiel de la Societe Française d'Electrotherapie, February, 1908.
[4] Rev. Crit. de Clin. Med., Nov. 10, 1906.

have been too few cases reported, to know whether the disease is permanently curable by this means. Improvement seems to be reasonably certain.

LOCOMOTOR ATAXIA

The author has seen remarkable and lasting benefit from *x*-ray and high-frequency applications to the region of the lumbar enlargement of the spinal cord. The applications should be localized, and mild and repeated ones are preferable to massive doses. Probably no cases have been permanently cured.

X-RAY TREATMENT OF FACIAL NEURALGIA

The *x*-ray examination having verified the clinical diagnosis of neuralgia without gross anatomic lesion, the therapeutic applications may be undertaken. The ray should be of a penetration of about No. 6 Benoist, an intensity of No. 5 Tousey, and the anticathode should be about 8 inches from the skin. Such an application may last about three minutes, equivalent to 1 H., and be given three times a week. A localizing shield and leather screen are desirable. The hair and eyes are to be protected, but, generally speaking, rather a generous area of the painful region is to be exposed. A three- to five-minute application of an ultraviolet ray glass vacuum electrode is to be made at the conclusion of each *x*-ray treatment.

A case of this kind was a lady about sixty-five years of age, referred to the author by Dr. W. T. Bull. She had suffered for twelve years from obstinate neuralgia of the upper jaw, which had not been relieved by a series of surgical operations. The *x*-ray examination showed normal bony conditions. Twelve *x*-ray and high-frequency treatments were given as indicated above, the *x*-ray shining right through the cheek and lips. She had to leave the city at the end of this time on account of the summer heat. The pain had then been only somewhat relieved, but Dr. Bull reported to me the following winter that the pain had entirely disappeared during the summer and had shown no sign of recurrence.

The following is a case in which there was a deep-seated lesion which could not be reached by remedial agents: The patient, a lady of about thirty-eight, was brought to the author by Dr. W. K. Draper, with a history of the most severe pain, especially in the region of the right eye and temple and right side of the forehead. A supra-orbital neurectomy had given no relief. Blood examinations had shown a marked degree of anemia, which had yielded only partly to medical treatment; *x*-ray examinations failed to show any lesion in the jaw, antrum, or frontal sinus. The treatment was chiefly by static electricity and high-frequency currents from ultraviolet ray vacuum electrodes. In addition there were a sufficient number of *x*-ray applications for diagnosis and treatment to produce an effect in a case amenable to them. There was marked improvement for awhile, but never complete disappearance of pain, and at the end of a thorough trial the treatment was abandoned. The severity of the symptoms and the patient's poor general condition led to the conclusion that some very grave though obscure malady existed. Death ensued and an autopsy revealed a tumor of the right parietal part of the brain with considerable softening around it.

Leonard[1] has also applied the *x*-ray in cases of migraine, tic douloureux, and facial neuralgia, generally with success. There was recur-

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[1] Medical Record, July 15, 1905.

rence in one or two cases, but in most cases the relief seemed to be permanent.

X-RAY APPLICATIONS AFTER NERVE RESECTION FOR TIC DOULOUREUX

A case recently under treatment by the author was referred by Dr. A. H. Ely after operation by Dr. Harvey Cushing. As great a portion as practicable of the inferior dental nerve had been resected from the inside of the mouth. Six months later there had been some return of pain, but not much return of sensation in the portion of the lip supplied by the inferior dental nerve. A few months ago *x*-ray treatment was begun, with a view to a retarding influence upon the regeneration of the nerve and, if possible, to prevent bridging over the gap by newly formed nerve-fibers.

The applications have been made both externally and inside the mouth. For both the *x*-ray tube has been enclosed in a Ripperger shield and a cylinder diaphragm has been used. The distance from the anticathode of the Friedlander heavy anode tube (same model as the Müller No. 13) to the outer or inner surface of the jaw has been 13 inches. A 12-inch induction-coil was used with the 110-volt direct current, a Wappler mechanical interrupter, 12-ohm resistance in rheostat, 3 amperes primary and 1 ma. secondary current. Rays, No. 6 Benoist; intensity, No. 7 Tousey. In the course of twelve days the application was of sixteen minutes' duration, on an area 3 inches in diameter on the outside of the face and 10 minutes on an area 1 inch in diameter on the inside of the jaw. Three minutes of either application was equal to 1 Holzknecht unit. The first course of treatment then applied 6 H. externally and 3½ H. internally in six different applications made during twelve days.

The effect from some of the earlier applications was to cause complete disappearance of the pain, but the later applications of the first course of treatment were followed by a sort of stimulation of the nerve, causing temporary pain.

The pain at every stage of the case came in paroxysms, and was located immediately behind the last lower molar tooth. The patient said it was just as if the lighted head of a match had broken off and landed on the gum. Treatment, in another city, by radium and by the *x*-ray had been unsuccessfully tried before an operation was resorted to.

There seems reason to hope for success from the application of the *x*-ray after resection of the nerve, but the value of the method has not yet been proved.

Treatment was begun Feb. 8, 1908, and as far as practicable has consisted of a series of courses of treatment, during which 6 Holzknecht units have been applied both outside and inside in about three weeks, and then an intermission of three weeks has been allowed. On July 20, 1908 the outlook seemed very favorable, and the patient passed the first entirely comfortable day for over a year. Twinges of pain when they did occur were much lighter than formerly. The patient characterizied them as *sensations rather than pain.* A vacation from treatment during the summer was followed by a recurrence, which did not yield promptly, and the patient abandoned treatment and had an operation by alcoholic injection, which I believe has given encouraging results.

PROSTATIC HYPERTROPHY

The author has treated several cases and in some a few *x*-ray treatments have produced a marked reduction in the amount of residual urine and a return of the ability to urinate without a catheter. The method has been by allowing the *x*-ray to shine over the perineum in the direction of the prostate, the scrotum, anus, and buttocks being protected by a localizing shield surrounding the *x*-ray tube. Mild applications of rather a penetrating ray, No. 7 Benoist, are made every other day, so as to apply 5 Holzknecht units in about two weeks. Treatment may be intermitted upon the appearance of slight redness.

There is no danger of inducing sterility if the *x*-ray does not shine directly upon the testicles. Men for whom the author has had to make long and strong applications to one testis while shielding the other with sheet lead have subsequently married and had strong healthy children.

Moskowicz and Stegmann[1] report 6 cases treated successfully. At the end of one or two weeks' treatment the prostate became softer and a little sensitive to pressure. Most of their patients had some uncomfortable symptoms for a time, frequent desire to urinate, a sensation of weight in the perineum, and sometimes rectal tenesmus. Some cases also showed an increase in the existing cystitis, an increase in the amount of pus, and even a little blood in the urine. One patient developed slight epididymitis. All these symptoms were slight and of short duration. They were attributed to an irritation caused by the rapid destruction of the glandular epithelium. In some cases there was the same temporary toxemia which characterizes the application of the *x*-ray in cancer and leukemia, but this also was mild.

All their cases were successful, but the most rapid cases were those which had only been compelled to use a catheter for a short time and who had not developed cystitis or vesical paralysis.

Moskowicz and Stegmann[1] made their applications through a Kelly rectoscope 9 cm. long and with its inner end cut obliquely so as to expose a larger surface. The rectoscope is held in place by strips of adhesive plaster and the neighboring surface is protected by sheet lead. The *x*-ray tube is placed so that its anticathode lies in the direction of the axis of the rectoscope and at a distance of 40 cm. (16 inches) from its orifice. Their exposures lasted fifteen minutes, and two or three applications were made at intervals of two or three weeks.

Drs. Turaschi and Carabelli[2] report several cases treated, with fine results. Their method was by application over the perineum, protecting the scrotum from the rays.

My own cases of tubercular and other prostatitis were treated with the patient lying upon his back, the legs bent up, and the hips near the edge of the table. A localizing shield enveloped the *x*-ray tube and afforded general protection. The exact area of application was secured by cutting a suitable orifice in a sheet of *x*-ray metal spread over that part of the patient.

A sole-leather disk covered the orifice of the localizing shield and arrested the less penetrating rays, which otherwise would have been absorbed by the skin and would have produced irritation.

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[1] Münch. Med. Woch., June 18, 1905.

[2] International Congress of Physiotherapy, Liege, August, 1905.

X-RAY TREATMENT OF GOITER

The method of aplication is to allow rays of a medium degree of penetration (No. 6 or 7 Benoist) to shine upon the front and sides of the neck from two or three different directions. A localizing shield is used to limit the rays to the proper region, and a sole-leather disk may be used to absorb the less penetrating rays. It may be necessary to wrap the chin in sheet lead, and it may be wise to cover one side of the neck with sheet lead while the other side is being treated. It is difficult, with the localizer alone, to limit the ray so exactly that there will not be a double effect along the median line from two successive anterolateral exposures.

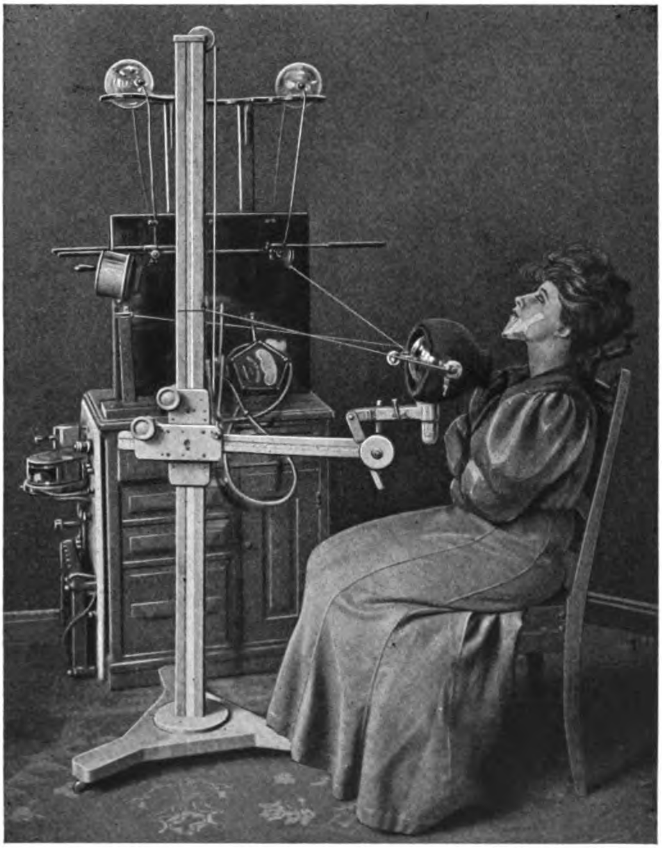

Fig. 747.—*X*-ray treatment of exophthalmic goiter. Brickner's tube-stand. Friedlander shield. Point of chin still further protected by *x*-ray metal.

Mild repeated exposures are to be preferred—½ to 1 H. twice a week. This is equivalent to an intensity of No. 5 Tousey for two to four minutes at a distance of 10 inches from the anticathode. Each of the two or three parts of the surface successively exposed is to have this amount of treatment at each session.

The results are somewhat uncertain, although the treatment is successful in a sufficient proportion of the cases to cause it to be recommended.

An experiment was performed by Drs. Luraschi and Fiorentini upon three puppies, all of whom had goiter. One of them was killed and the tumor examined under the microscope. Another was kept as a control and the third was subjected to *x*-ray treatment. This one died of asphyxia after a few treatments, and a microscopic examination showed that the *x*-ray had produced no effect upon the goiter.[1]

Fig. 748.—Exophthalmic goiter. Treatment by high-frequency currents applied by ultraviolet ray vacuum electrode.

Michaux has treated cases of goiter and obtained results in the hypertrophic variety, but the growth recurred when the treatment was stopped.[2]

Kobolko, on the other hand, reports a case of goiter cured by the *x*-ray.[3]

A glandular swelling in the neck may, of course, be one of the lesions

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[1] Le Radium, Sept. 15, 1905, p. 300.

[2] Ibid.

[3] Ibid.

of leukemia or pseudoleukemia, and in that case the x-ray produces positive results.

Two other cases of goiter have been treated with benefit by Stegmann.[1] Six treatments in one case and two in the other led to softening and reduction in size without any systemic disturbance.

Stegmann did not notice the special susceptibility of the skin to the x-ray, which has been described by Görl.

Exophthalmic Goiter.—Mild repeated applications of the x-ray over the thyroid gland and of a vacuum electrode from the Oudin resonator over the entire neck resulted in the cure of a case brought to the author by Dr. Love. Before treatment the pulse was never below 130; there was such tremor of the hands that she could not pour a cup of tea, and such palpitation of the heart that it shook the whole bed and kept her husband awake at night.

Treatment was continued for about three months, and when the patient returned to her home in North Carolina her pulse was 90 and all the ocular and nervous symptoms had disappeared. The thyroid gland had diminished in size. It had never been very large.

No recurrence took place even during a period of great anxiety over her sick child the following year. The patient was examined three years later and was perfectly well.

The method of application of the x-ray is shown in Fig. 747 and of the high-frequency current in Fig. 748.

Rontgenization of the suprarenal capsule in high arterial tension produces a decided fall and an improvement in the symptoms.[2]

PERNICIOUS ANEMIA

This is a disease in which the effect of the x-ray upon the blood-forming organs, the spleen, and the marrow of the long bones may sometimes be of great benefit. The danger of causing toxemia and possible death makes it necessary to use extremely small doses at the commencement, and some observers (Pancoast) consider the x-ray absolutely contraindicated on account of the danger. Injections of diphtheria antitoxin in addition to the x-ray have been used successfully by Renon and Teixier.[3]

HODGKIN'S DISEASE AND PSEUDOLEUKEMIA AND LYMPHOSARCOMA

These are all diseases in which x-ray applications to the affected glands is of marked benefit, and, except in lymphosarcoma, it seems probable that permanent cures may be obtained in many cases, or that the others may be kept in good health by continuing the treatment at intervals. The beneficial effect of the x-ray is due to a direct action upon lymphoid tissue and to an effect upon tissue ferments (Edsall). The affected lymphatic glands become a great deal smaller and the microscopic appearance is changed. There is a destruction and disintegration of lymphocytes with the presence of masses of chromatin derived from their nuclei. The gland may finally change to a fibrous nodule.

In a case of Hodgkin's disease, treated by Roth,[4] the glands were

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[1] Münch. Med. Woch., June 27, 1905.

[2] A. Zimmern and C. Cottenot, Wein. klin. Woch., No. 18, 1912.

[3] Le Progrés medical, March 31, 1906.

[4] Jour. Amer. Med. Assoc., p. 1263, Oct. 20, 1906.

reduced to a normal size by *x*-ray treatment every other day for about three months. A medium hard tube was used, with the anticathode at a distance of 10 inches from the skin over the neck and manubrium sterni (there were enlarged mediastinal glands), and the duration of each exposure was from ten to thirty-five minutes, divided up over different glands. Two or three recurrences took place requiring fresh courses of treatment. Senn and Pusey were among the earliest to treat these conditions by the *x*-ray. Pancoast has collected the reports of 44 cases treated up to 1907, and finds for this general group of diseases of the lymphatic glands without marked blood changes *x*-ray treatment in 29 cases, of which the final outcome is known, has given 25 per cent. of cases which are alive and apparently well from one to four years after the first symptomatic cure, and 60 per cent. have died, while 2 of the 4 cases still under treatment are likely to die and the other 2 seem likely to get well.

Rosenberger[1] has treated one case of pseudoleukemia with some reduction in the size of the spleen, but without much general benefit.

Two cases of pseudoleukemia treated by Krause[2] showed prompt improvement, while no result was obtained in 2 cases of lymphosarcoma, 1 case of splenic anemia, and 3 cases of chronic splenomegaly.

In no case did the treatment have any serious secondary effect.

Two methods of dosage are available. According to one method, 3 to 4 Holzknecht units of rays No. 8 Benoist should be applied over each glandular mass once a week unless contraindicated by the appearance of dermatitis. According to the other method, smaller doses of 1 Holzknecht unit should be applied over each glandular mass three times a week.

When using either method exposure of the abdomen should be undertaken with caution. There is not the same special danger of toxemia as in leukemia, but still the danger is great enough to make it desirable to ascertain the condition of the kidneys before making the exposure, and the first one should be short.

The distance and the strength of current and duration of exposure mentioned under the head of Leukemia (p. 1096) are suitable here.

The difficulty of differential diagnosis between lymphosarcoma and Hodgkin's disease adds a further element to the uncertain prognosis which must be given in these cases.

POLYCYTHEMIA

The results of *x*-ray treatment in this disease have not been decisive, but still *x*-ray exposures of the splenic area have produced some improvement and no accidents in 4 reported cases.

X-RAY TREATMENT OF LEUKEMIA

The credit of first reporting the treatment of a case of leukemia by the *x*-ray is generally accorded to Senn, but Pusey, Childs, Dunn, and others treated cases at about the same time. The treatment, therefore, is of American origin, but it has been adopted in every country and has been made the subject of over one hundred articles by various authors.

It was at once found that the majority of the cases improved in a most remarkable way if the *x*-ray was applied repeatedly to the enlarged

[1] Münch. Med. Woch., Jan. 30, 1906.
[2] Berlin. klin. Woch., p. 580, May 8, 1905.

spleen, any enlarged lymphatic glands, and the long bones. The number of leukocytes diminished from 200,000 or more to the normal 4000 or 5000, and the general condition of the patients became so much better that they were called symptomatically cured. The spleen often diminished to its natural size, but this effect was not so uniform as the effect upon the blood and lymphatic glands and upon the general condition.

The treatment required frequently repeated application for several months or a year.

The results were found to be permanent in only 1 case in about 15. As a rule, recurrence and death took place. There were bad effects in certain cases which were described on pages 1033 and 1096.

Nevertheless, the *x*-ray produces an improvement which nothing else ever did, and it seems to be the proper treatment for this disease. It is not unlikely that improvements in the mode of application may result in saving more lives than the 6 or 8 per cent. shown by the record to-day. Pancoast's method of application to the long bones instead of to the spleen may prove to be a step in advance.

The close analogy between leukemia and sarcoma makes it seem possible that leukemia also will prove to be incapable of permanent cure in the great majority of cases. This is a point which the future will decide. It does not at all imply that the *x*-ray is not the best treatment that we know of. The *x*-ray ought to be applied in every case unless contraindicated.

X-ray applications in leukemia suppress fever when this is present, and also night-sweats, apathy, and anorexia. As a rule, the cachectic appearance, the color and dyspnea, and insomnia all begin to improve inside of two weeks. Albuminuria, if present, rapidly disappears, but edema is slower.

The *x*-ray is more constant in its results upon the myeloid than upon the lymphoid variety of leukemia.

Examples of the Results.—Krause[1] reports the treatment of 6 cases of myelogenous leukemia; 5 of these showed rapid improvement, reduction in the number of leukocytes, increased number of red blood cells, increased globular value, diminution or complete disappearance of the splenic tumor, increased bodily weight, marked improvement in general health. The remaining case of myelogenous leukemia was complicated by hemorrhagic nephritis and was not influenced by the *x*-ray treatment.

Out of 4 cases of leukemia (myelogenous?) treated by Melland,[2] 3 were benefited by the *x*-ray.

Hynck[3] has not obtained permanent results from the treatment of leukemia (myelogenous?) with the *x*-ray, but, at the same time, the condition of the blood and the spleen showed the improvements noted by other observers, and there was the same improvement in the general health.

Rosenbach[4] believes that the reduction in the number of leukocytes is not due merely to the destruction of leukocytes and erythrocytes in the blood, but also to the migration of great numbers of leukocytes into

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[1] Berlin. klin. Woch., May 8, 1905, p. 580; reviewed in Radium, Sept. 15, 1905, p. 314.

[2] British Med. Jour., July, 1905.

[3] Wiener Med. Woch., June 10, 1905, p. 1233.

[4] Münch. Med. Woch., May 30, 1905, p. 1055; reviewed in Radium, Sept. 15, 1905.

the irritated skin and subcutaneous connective tissue. The products of the destruction of the leukocytes probably have an inhibitory effect upon the production of leukocytes.

According to Rosenbach, the *x*-ray acts upon a symptom, not upon the cause, of the disease. He thinks it may even be that the great number of leukocytes is a defensive provision of nature in this disease.

A case of splenomyelogenous leukemia was treated by Roth[1] by *x*-ray applications over the spleen and the long bones alternately. The primary effect of the *x*-ray was to increase the number of white cells, which reached its maximum five hours after each exposure. The number of leukocytes steadily increased from 135,000 before treatment to 378,000 after the first month's treatment. From this time on there was a steady fall in the number of leukocytes, aided toward the last by the use of Fowler's solution of arsenic. After a year's *x*-ray treatment, and a month after the arsenic had been stopped, the leukocyte count was normal, but the size of the spleen was not greatly changed. The primary increase in the number of leukocytes was accompanied by a great number of degenerate cells, principally disintegrating myelocytes, which in many cases consisted merely of a network of fibrillæ. The amount of hemoglobin remained uniform at 70 per cent. during a whole year's *x*-ray treatment, but promptly rose to 80 per cent. when arsenic was added to the treatment. The dosage of the latter was at first 5 drops of Fowler's solution three times a day, and this was gradually increased to 15 drops three times a day.

Buchanan[2] finds that *x*-ray applications reduce the number of leukocytes, and that this is due partly to a destruction of the leukocytes circulating in the blood, the effect being chiefly upon those which normally respond to basic dyes. He regards the effect as also partly one upon the marrow of the bones. He notes a rapid increase in the number of myelocytes after *x*-ray treatment is discontinued.

Roger S. Morris[3] notes the effect of long *x*-ray exposure (three to five hours) in healthy rabbits and rats. There is a reduction in the number of leukocytes, the lymphocytes being chiefly affected. There is no effect upon the number of red blood cells or upon the amount of hemoglobin.

It must be remembered that a sudden fall of perhaps 200,000 leukocytes is not an unheard of thing in leukemia without special treatment.

Dock[4] has made valuable observations upon the clinical benefit and pathologic findings in cases of leukemia treated by the *x*-ray. He found that the myelocytes rarely disappeared.

Gramegna and Quadrone[5] and L. d'Amato[6] found that *x*-radiation of the spleen led to a perceptible increase in the number of leukocytes, notably of lymphocytes, apparently by contraction of the organ. The blood of the spleen examined in 3 patients showed a large proportion of lymphocytes, some multinuclear myelocytes, a small number of multinuclear cells and of myelocytes and of nucleated red blood cells, the number being superior to that found in the circulating blood. The serum had a slight agglutinative action, but no hematolytic or leukocytic action.

[1] Jour. Am. Med. Assoc., Oct. 20, 1906, p. 1264.

[2] British Med. Jour., July 14, 1906.

[3] American Medicine, Dec. 2, 1905.

[4] Ibid., Dec. 2, 1904.

[5] Arch. generales de Medicine, 1905, p. 2568.

[6] Zeitsch. f. klin. Med., 57, 233, 1905.

The abnormal relations between the various forms of leukocytes persist even though their total number is so markedly reduced.

Effect Not a Bactericide One.—The benefit in leukemia does not seem to be due to a bactericide action, for the *x*-ray is only weakly effective in this direction, and then we do not know that the disease is of parasitic origin.

Nature of the Beneficial Action.—The favorable effect of the *x*-ray in splenic and lymphatic diseases (including leukemia and pseudoleukemia) is explained by Krause and Ziegler on the ground that the application destroys the pathologic lymphoid tissue.

Edsall attributes the beneficial effect to an action upon the tissue ferments.

The Nature of the Leukocytosis in Leukemia.—Large lymphocytes form 90 per cent. of the total number of leukocytes; small lymphocytes, 4 per cent., polymorphonuclear leukocytes, 4 per cent.; myelocytes, 2 per cent.; eosinophile, 0.5 per cent.; no basophiles or eosinophile myelocytes (Mendelson and Sondern). These observers found that on the day of death the large lymphocytes fell to 30 per cent., while the small lymphocytes increased to 53 per cent.

A simple count of the number of leukocytes is not regarded as sufficient; there should be also a differential count in cases of leukemia under *x*-ray treatment.

Ledingham[1] treated a case of splenomyelogenous leukemia with marked general improvement in the condition of the blood. The patient died of the grip, and a post-mortem examination showed that Malpighian corpuscles were absent from the spleen and that lymphoid tissue was very scarce. The most remarkable change consisted in the substitution of proliferating undifferentiated basophile myelocytes for the fully formed neutrophile cells usually found in the spleen in leukemia. The profoundness of the changes in the spleen caused Ledingham to recommend caution in the application of the *x*-ray after the leukocytes had been reduced to the normal number.

Holding and Warren[2] report temporary improvement in a case of pseudoleukemia and in one of leukemia. The treatment was applied to the spleen, the enlarged glands, and the epiphyses of the long bones (elbows and knees especially). The blood showed the improvement reported by so many other observers. A careful examination of the urine showed an increased amount of uric acid and a high ratio of uric acid to urea during periods of active *x*-ray treatment, but Holding and Warren were unable to trace any relation between the leukocyte chart and the urinary analysis, as above, or as regards the uric acid and purin excretion.

The increased coagulability of the blood produced by *x*-ray exposures has been suggested as of possible value in hemophilia and other hemorrhagic conditions.[3]

Effects of *x*-Ray Treatment Upon Excretion of Uric Acid in Leukemia.—The majority of observers, including Pancoast, find that the amount of uric acid in the urine is increased by the treatment, and regard the treatment as contraindicated if the amount of uric acid in a twenty-four-hour specimen falls after the *x*-ray exposure.

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[1] Lancet, Feb. 10, 1906.

[2] New York Med. Jour., Nov. 11, 1905.

[3] Gramegna and Quadrone, Arch. Gen. de Med., 1906.

It is noteworthy, however, that another observer has arrived at a contrary conclusion:

The reduction in the amount of uric acid in the urine, which is a consequence of increased oxidation and other vital processes, is regarded by Rosenberger[1] as an important indication of the benefit of x-ray application in leukemia. If the amount of uric acid fails to be reduced he thinks that especial caution should be used in applying this method of treatment. According to this observer there is a change in the excretion of uric acid in cases of leukemia treated by the x-ray. The amount is increased at first, then diminished, and then returns to about the normal. The excretion of xanthin is increased throughout the treatment. He finds no such change in the urine in cases of pseudoleukemia or diseases other than real leukemia treated by the x-ray.

Chemic and Histologic Researches in Patients with Leukemia Treated by the x-Rays (Lossen and Morawitz[2]).—They record a case of myeloid leukemia treated by x-rays, and in which there was a return to the normal number of leukocytes at the same time that the excretion of uric acid returned to the average. $\left(\frac{\text{N}}{\text{uric acid}} = 30\right.$, instead of 13, as it was at first.)

These facts indicate a diminution in the activity of the tissues producing leukocytes. These authors insist on this retrogression of the leukopoietic functions. In certain cases, however, the diminution in the leukocytes is not accompanied by a lowering of the uric acid ratio. Sometimes one can see developed in patients treated by the x-ray an aplastic leukemia which is dependent upon the hypoplasia of the leukopoietic organs produced by the x-rays.

Development of a Leukotoxin from x-Ray Exposure.—Milchener and Wolff[3] found that x-ray exposure of the spleen after removal from the living body produced a leukotoxin. An extract of such a spleen injected into a healthy animal produced a marked reduction in the number of leukocytes, while a similar injection from a spleen which had not been x-rayed produced leukocytosis, increasing the number of white blood-cells.

Exposure of living animals to the x-ray produces a reduction in the number of leukocytes, especially if the blood-forming organs, the spleen and bone-marrow, are exposed. The fact that the primary effect is followed by a renewal of the number or even an increase over the original number of leukocytes is taken by some authorities to indicate that the effect is a direct one upon the leukocytes and not a depressant one upon the blood-forming organs. Other observers, like Iwan Rosenstern,[4] consider it due to the effect upon the leukocyte-forming organs, and that the number of leukocytes is reduced not by their destruction, but by their greatly restricted production.

The observations of Capps and Smith[5] show that serum from a leukemic patient who has been treated by the x-ray produces a marked reduction in the number of leukocytes if injected into another leukemic patient. This leukotoxin is strongest when the patient has responded

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[1] Münch. med. Woch., vol. liii, No. 22, 1906.

[2] Deutsch. Arch. f. klin. Med., 83, 288, 1905.

[3] Berlin. klin. Woch., vol. xliii, No. 24, 1907.

[4] Münch. Med. Woch., May 29, 1906.

[5] Transactions Am. Röntgen Ray Soc., 1906, p. 1906.

best to x-ray treatment. The action is selective, affecting mononuclear leukocytes more than polynuclear ones. Its repeated injection into another patient produces a kind of immunity, so that it is not followed by as great a reduction in the number of leukocytes as it caused at first.

This same serum possesses marked leukolytic and agglutinating effects upon blood *in vitro*. Phagocytosis is not affected by the serum from a patient who has been x-rayed.

Accidents Which Have Followed x-Ray Treatment in Leukemia.—*X-ray dermatitis* over the spleen has been observed by so many operators that it seems as if some special susceptibility must exist. One precaution which may be taken consists in the use of a screen of leather, wet or dry, or four thicknesses of diachylon plaster, as a means of arresting the soft rays, which would otherwise be absorbed by the skin and set up dermatitis and which have no curative influence in leukemia. The position of the tube has a great deal to do with the effect upon the skin. In some reported cases the x-ray tube has been placed 10 cm. (4 inches) from the surface of the body. A burn was a natural consequence if enough x-ray was applied to affect the deeper parts of the spleen, situated two, three or four times as far from the x-ray tube. The rays are then four, nine, or sixteen times as concentrated at the skin surface as they would be at the deeper parts of the spleen if the matter of distance were alone operative. But to this we have added the effect of absorption by the superficial tissues. The anticathode should be placed at a distance of from 13 to 16 inches from the cutaneous surface in treating the spleen. The rays should be of a fair degree of penetration, about No. 7 Benoist. Dosage is of vital importance, and either long experience or the use of such a means of measurement as the Sabouraud and Noiré radiometer or the author's intensimetric units should be depended upon to secure the correct dose. To apply the x-ray even for what seems to the operator to be a short time is dangerous if he has no means of knowing the strength of the ray produced. It is like administering a teaspoonful of medicine from a little bottle marked "Solution of Morphin" without knowing whether it is a weak solution, of which a teaspoonful is a moderate dose, or a strong one for hypodermic administration, and of which 8 drops will render a person unconscious and a teaspoonful might easily be fatal. The operator may know that with his apparatus regulated in a certain way, so as to give a certain number of amperes with a certain rate of interruption in the primary current and a certain resistance in the tube resulting in a certain number of milliamperes of secondary current, a certain number of minutes' exposure at a certain distance constitutes a desirable application. This knowledge he may have gained by experience or by the use of the quantitative or intensimetric systems so often referred to in this book. If he does not know the safe dose of the rays generated he had better make the quantitative or intensimetric measurements for the special case in hand. The theory that the x-ray does not burn, but rather an electrostatic or condenser condition of the air separating the x-ray tube from the skin, and that burns may be prevented by placing the x-ray tube at the proper distance (13 to 16 inches) to overcome this effect, is not to be relied upon to the neglect of proper dosage. Burns have occurred in cases in which this theory as to distance has been exclusively depended upon. The cumulative effect of the x-ray is always to be borne in mind. Exposures which individually might produce no visible effect might produce bad burns if repeated day after day for a great many weeks. This is where the exact knowledge of dosage is most important.

A case of Liebermeister's, a woman of sixty, showed cardiac weakness and additional swelling of the glands and died after *x*-ray exposure for Hodgkin's disease. Pleurisy with effusion followed *x*-ray exposure for leukemia in two of Quadrone's patients. Such accidents as these suggest caution in commencing this treatment upon a new patient whose degree of susceptibility is unknown.

The *toxemia* which often follows *x*-ray exposures in this disease, and which has been made the subject of admirable studies by Edsall and others, is described on p. 1033. A case in which Pancoast made a single radiographic exposure of eight seconds preliminary to any therapeutic application showed pronounced and almost fatal toxemia. This condition appears to be due to the inability of the kidneys to remove the enormously increased products of destructive metabolism. It may be guarded against in two ways: First, by making sure that the kidneys are in a healthy and active condition before applying the *x*-ray, and, second, by commencing with extremely small doses. Pancoast's suggestion as to avoiding the spleen in the first few weeks or months of *x*-ray treatment for leukemia certainly tends to prevent the occurrence of extreme toxemia, though this is not its only object.

In occasional cases of leukemia treated by the *x*-ray a rapidly *fatal anemia* has followed.

Contraindications.—The *x*-ray comes into play especially in cases where abnormal cellular activity and development are taking place, and is contraindicated where profound depression of cellular life has taken place, as in the marrow of the long bones in pernicious anemia.

Insufficiency of renal activity is a contraindication.

Technic of *x*-Ray Application for Leukemia.—Two principal methods have been used for the application to the spleen and the enlarged glands: (1) Belot and others in Europe make applications of 4 or 5 Holzknecht units over the entire surface of the spleen once a week until stopped by the development of dermatitis, which seldom occurs. To secure uniformity of effect the tube is about 8 inches from the skin and the surface is *x*-rayed in four sections, three being protected while one is exposed. The entire four sections are treated at the same session. Belot has not observed any cases of toxemia from this method, but in America it is regarded as extremely hazardous in an untried patient. Fatal toxemia has been observed from a single application of this strength in leukemia. There is not so much danger in the same application to the lymphatic glands, but even here it is risky at the first treatment. (2) The method of daily application of fractional doses of about ¼ to ½ Holzknecht unit over the spleen and lymphatic glands is usually safe, provided the urine has been analyzed and the kidneys found to be normal.

The rays should have a penetration of about No. 7 Benoist, and an example of technic producing ½ H. is as follows:

Müller heavy anode tube 6 inches in diameter, 12-inch induction-coil with great self-induction; Caldwell interrupter, 8 amperes current, 2 ma. secondary current; No. 8 Benoist, 3½ inches parallel spark-gap, 1 anode used; intensity of rays, No. 11 Tousey; no rheostat resistance; distance from anticathode to skin 12 inches; an exposure of three minutes equals ½ H.

An exposure of six minutes under the same conditions equals 1 H.

The daily dose varies between these amounts in different cases.

The duration of exposure would be doubled if the treatment were given only every two days.

Another example of dosage employs the same x-ray tube and coil, a Wappler mechanical interrupter, 3 amperes of primary current, 1 ma. of secondary current, rays No. 5 Benoist, resistance 3 inches, 12 ohms rheostat resistance, no spark-gap, anticathode and accessory anode, connected distance from anticathode to skin 12 inches; an exposure of five minutes equals about 1 Holzknecht unit.

Another example of dosage (quoted from Pancoast) employs a hard tube, resistance 4 inches, an induction-coil with a mechanical spring interrupter, and a secondary current of 1 ma. Four minutes' exposure over the abdomen at a distance of 9 or 10 inches is a very mild exposure, but still was enough to cause profound toxemia in a case of pernicious anemia. Ten or fifteen minutes is a regular therapeutic dose employed by Pancoast. Attention is to be called to the fact that he no longer makes the application to the spleen, not at the start, at all events.

Röntgenization of the Long Bones Instead of the Spleen in Leukemia.—This is a method adopted by Pancoast[1] in the effort to find a means of permanent cure instead of temporary benefit, and it is a method which seems to be less likely to be accompanied by distressing accidents than the older method.

The same daily applications are required, and the same quality and intensity of radiation, and the same distance and duration of exposure. The spleen is not exposed, and should be protected by x-ray metal if an x-ray tube is used without a localizer. His method is to make daily exposures of both knees, for instance, for three days, which usually causes a reduction in the number of leukocytes, a fourth exposure being sometimes required. The different parts of the skeleton receive successive courses of exposure, even the dorsal vertebra being treated. After making a complete round in this way, the same process is repeated, and it may be that several rounds will have been gone through before any applications are made to the spleen.

The result is a progressive reduction in the number of leukocytes and a return to the normal differential count. The spleen does not show nearly as rapid a change as when it receives direct applications, but, none the less, it gradually diminishes in size. Exactly when to begin x-raying the spleen is a matter of judgment in individual cases.

The guiding principle seems to be that the spleen should not be x-rayed as long as it is practically a great mass of degenerate leukocytes, ready to break down under the x-ray, and cause toxemia from overloading the excretory functions. The theory assumes that the spleen does not produce these degenerate leukocytes, and that treatment of the spleen merely destroys them without reaching the cause of their abundance. The application to the marrow of the long bones is supposed to exert a curative influence upon the cause of the disease.

The results of this plan of treatment cannot yet be determined, but it seems to the author a step in the right direction.

The applications should be made with very great regularity, and no ordinary excuse should be accepted for taking a vacation of even as long as ten days at any time until the blood-count is normal.

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[1] Jour. Am. Med. Assoc., April 25, 1908.

Benzol as a Medicine for Leukemia.—Korányi of Budapest was the first to report upon the benefit to be derived from the internal use of this drug, and this fact has been verified by numerous other observers. A good mode of administration, suggested by Királyfi, is by capsules containing 7 grains of pure benzol and an equal quantity of olive oil. Two to ten capsules are taken after meals and the maximum dose is 75 grains (5 grammes) of benzol per day. The treatment is especially effective in cases previously treated by the Röntgen ray. The effect is chiefly that of reducing the number of leukocytes. Benzol is a drug to be used cautiously, and not for an indefinite period of time. Too great an effect causes severe or even fatal gastro-intestinal irritation.

The Gauss Method of Rontgenotherapy for Uterine Fibromyomata.—The use of hard rays filtered through 3 mm. of aluminum, with the tube rather close to the skin and the cross-fire principle to avoid repeated exposure of the same cutaneous surface, has led to greatly improved results by Krönig and Gauss in the Freiburg Clinic. They regard practically every case of myoma as curable in five weeks, but consider operation preferable if enucleation is possible without causing sterility, or if there is probably cancerous degeneration or gangrene or if the bladder is incarcerated.[1]

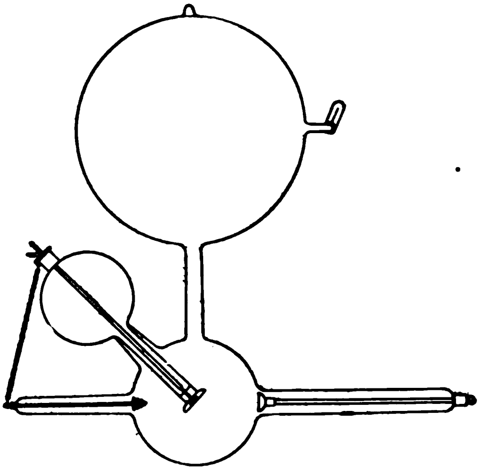

Fig. 749.—Water-cooled tungsten target tube for Gauss treatment work (Baker *X*-ray Co.).

Their technic[2] involves the use of a water-cooled tube with a 5-inch principal bulb, connected with a 7-inch accessory bulb, which increases the stability of the vacuum. They use a secondary current of 5 or 10 milliamperes sent through the tube in a succession of flashes by a rhythmeur. The tube is enclosed in a cup-shaped shield of lead glass, the orifice of which is covered by a screen of aluminum 3 mm. (or ⅛ inch) thick. The *x*-ray is applied to thirty or forty different areas of the abdomen, front and back. Each area is about 1 inch in diameter, and upon it is laid a Kienböck strip of photographic paper to test the dose applied. The skin immediately around this area is protected by a thick lead disk

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[1] A. Hamm, Therap. Monatshefte, xxvii, No. 7, Berlin, July, 1913.

[2] N. Y. Acad. Medicine, Obstetric and Gynecologic Section, Nov. 28, 1913.

with a hole 1 inch in diameter, and overlapping the edges of this are two L-shaped pieces of sheet lead, ⅛-inch thick, protecting a region of 1 foot square. Overlapping the lead is a protection of *x*-ray-proof fabric covering the entire trunk and head. They place the tube very near the skin to bring the anticathode as near as possible to the deep lesion, relying upon the thick aluminum filter to stop the rays which would chiefly affect the skin; and also upon the fact that the dose applied to the deep-seated lesion is divided among many different skin areas. Nevertheless, as measured by the photographic strip in contact with the skin, the dose applied by these operators at each spot appears to be several times the erythema dose as measured by the Kienböck sensitized paper. The reason this large dose does not produce a dermatitis in each place to which it is applied is because the thick aluminum filter has stopped all the rays which would be entirely arrested by the skin and permits the passage of rays which are approximately homogeneous. While they are arrested in part by every portion of substance through which *x*-ray passes, still there is no great part which stops right at the surface and exerts all its effect there.

Experiments with a Kienböck strip placed upon the surface, and another inside the uterus (after dilatation), have shown that one-quarter of the *x*-rays passing through 3 mm. of aluminum reaches the cavity of the uterus and one-half when 4 mm. are used.

The *x*-ray converges upon the uterus and ovaries from many different portions of the surface. Krönig and Gauss give a complete treatment at a single session, lasting perhaps three hours and requiring perhaps seven different *x*-ray tubes. This is repeated every three weeks until permanent amenorrhea is produced, and in 300 cases or more they have secured a complete cure. The cases in which amenorrhea is not secured are apt to have a return of the fibromyoma.

This method of very heavy dosage, even with filtered rays, is not to be rushed into without gradual, careful testing of the effects of such applications. Necrosis of the intestine has been reported in rare instances and also dermatitis.

Krönig and Gauss apply mesothorium and radium internally in many cases.

The method described marks a very great advance in Röntgenotherapy, but requires great study and experience.

EPITHELIOMA

The form in which the skin is not adherent or fixed to the underlying tissues is almost certain to be cured by *x*-ray treatment. This form is frequently met with near the inner angle of the orbit, and is microscopically the same as the intractable form occurring on the lip. The first form may exist for years without amounting to very much locally and without glandular involvement, and may be radically cured by caustics, excision, or the *x*-ray. The second form is clinically an entirely different disease. After reaching a certain stage it involves the tissues deeply, produces glandular metastases, has a tendency to destroy life, and is seldom completely cured by caustics, excision, or the *x*-ray. The first type occurs upon a dry cutaneous surface, the second usually at the mucocutaneous junction at one of the orifices of the body. The first may be called cancroid, as distinguished from the true cancer of the second type. In the first type, or skin-cancers, *x*-ray treatment is practically certain of success and gives a better cosmetic effect than any other kind of treatment.

Recurrence after surgical excision of an epithelioma of the face is frequently due to the fact that the surgeon has not gone beyond the infected area, being influenced by a desire for a cosmetic effect and to leave as little deformity as possible. Curetage, the galvanocautery, electrolysis, or mercurial cataphoresis also are liable to leave infected tissue for the same reason. The tissues which are not actually destroyed are sources of trouble unless the process has been applied beyond the infected area, and this it is often impossible to do without leaving undue deformity. The *x*-ray is not open to any such objection. It can be applied to a wide enough area to include all the infected tissue and some of the surrounding sound tissue in a case of epithelioma of the face, and in a strength suitable to the cure of epithelioma it does not destroy neighboring sound tissue. It is an ideal method from a cosmetic standpoint, and for the reason above stated a case of epithelioma of the face cured by the *x*-ray is much less liable to recur than one treated by the other methods mentioned.

Some caustics, like pyrogallic acid, have the property of destroying exposed epitheliomatous tissue without injuring the neighboring sound skin and are excellent from a cosmetic point of view. There is no such deformity as results from surgical excision, but there is not the same freedom from recurrence, which is the chief advantage of *x*-ray treatment.

According to Robinson, the *x*-ray as an exclusive treatment is most likely to be successful in the variety of cutaneous epithelioma known as rodent ulcer and in some cases of superficial prickle-celled epithelioma. He also regards certain cases of rodent ulcer, especially those of the crateriform variety, as incurable by the *x*-ray or any other known means. "Hard, firm, elevated epithelial margins must be made more vulnerable by injuring agents, such as caustics, before the *x*-ray is applied."

These are the cases in which, if the *x*-ray alone is depended upon, a more severe reaction than usual must be produced.

The high-frequency spark from a metal electrode is an excellent application for epitheliomata which do not yield readily to *x*-ray treatment, or which, from their very appearance, we know will probably not do so. It has been referred to elsewhere as an adequate exclusive treatment for non-malignant keratoses and for epitheliomata where the disease is entirely localized. It does not destroy the disease beyond the point of application and necrosis and, therefore, in certain cases it would not prevent recurrence unless the *x*-ray were also used.

Microscopic Changes in Cancer Under *x*-Ray Treatment.—Stewart[1] examined tissues from an epithelioma of the wrist of traumatic origin. The important changes found were fatty degeneration and vascularization of the epithelial pearls; leukocytic infiltration and carious degenerative processes leading to destruction of tissue; bodies indistinguishable from Plimmer's bodies multiplying as the epithelia degenerated.

The histologic changes in a case of epithelioma of the gum and hard palate treated by myself were chiefly those of leukocytic infiltration. The disease was not cured in this case, however, only held in check.

[1] Jour. Am. Med. Assoc., 1906.

Pusey has found that an effect is produced upon the morbid epithelial cells themselves, and consists in a primary stimulation followed by degeneration, absorption, and disappearance, and their replacement by connective tissue derived from the healthy stroma. Endarteritis is produced in the smaller vessels in immediate relation with the tumor.

Effect of Alcoholism.—Alcohol used in excess is injurious in cases of epithelioma, especially in elderly persons, and interferes with the efficacy of x-ray treatment.[1]

Application of a Caustic Before x-Ray Treatment of Epithelioma.—A saturated solution of chlorid of zinc is an excellent caustic for removing part of a growth or for rendering an indurated growth more susceptible to x-ray treatment. It forms a dry eschar, but has no selective action upon the diseased tissues, such as that exerted by pyrogallic acid.

Fig. 750.—Epithelioma of forehead and nose before Röntgen ray treatment.

Fig. 751.—Epithelioma of forehead cured by Röntgen ray treatment. The nose was subsequently treated successfully.

Flat Surface Forms of Epithelioma.—A case of this kind was successfully treated by the author at St. Bartholomew's Clinic. There was an ulcerated surface, looking like the sluggish raw surface sometimes left by a burn, over the trapezius muscle on one side of the neck. The patient was a man sixty years old, and this had begun as a small pustule and had gradually extended until it measured 1 inch by 2 inches. Applications were made by a Green and Bauer heavy anode x-ray tube 6 inches in diameter, enclosed in a Friedlander shield and excited by an 8-inch induction-coil with a Caldwell interrupter and a primary current of 4 amperes. The rays were of penetration No. 6 Walter. Exposures of two minutes three times a week, at a distance of 9 inches, were made

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[1] A. R. Robinson, New York Medical Journal, Dec. 29, 1906.

until a slight reaction occurred, and were then reduced in frequency. It took about seven months to effect a cure in this case.

Fig. 752.—Chronic induration and ulceration of the face lasting ten years and recurring after healing under the *x*-ray. Finally excised.

The case shown in Fig. 752 was peculiar. Following a scratch received when the patient was a girl twelve years old an indurated and ulcerated spot had persisted for fourteen years. This disappeared under *x*-ray applications made with the tube in a localizing shield (Fig. 754), with the face further protected by sheet lead, through which a hole was cut considerably larger than the lesion. A piece of adhesive plaster fastened the lead to the skin around the lesion, the latter being left entirely exposed.

During the course of a couple of years there were recurrences and repeated *x*-ray treatment and, finally, surgical excision. Unfortunately there was no microscopic examination. There has been no recurrence.

Epithelioma Near the Ala of the Nose.—The following was such a case, the patient being a lady sixty-seven years old, whose father had suffered from a similar trouble, resulting in the loss of the entire ala of the nose. Hers began three years ago as a small abrasion and growth under the right eye and which gradually reached the condition present when she was sent to me. It was about the size of the meat of an almond, covered by a thick scab, which fell off about every four days, exposing

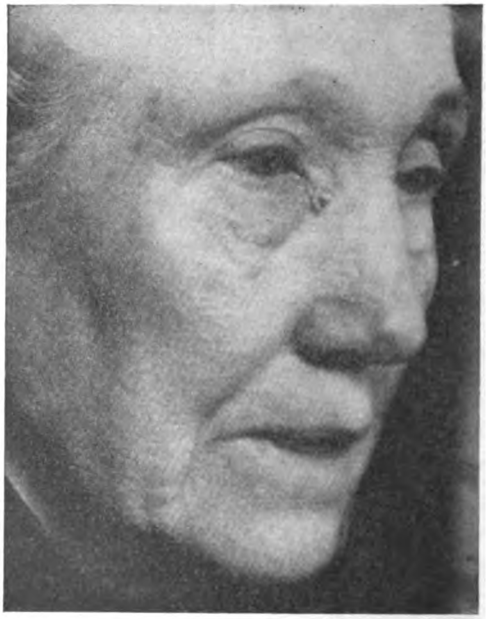

Fig. 753.—Epithelioma near inner canthus. Cured by Röntgenotherapy.

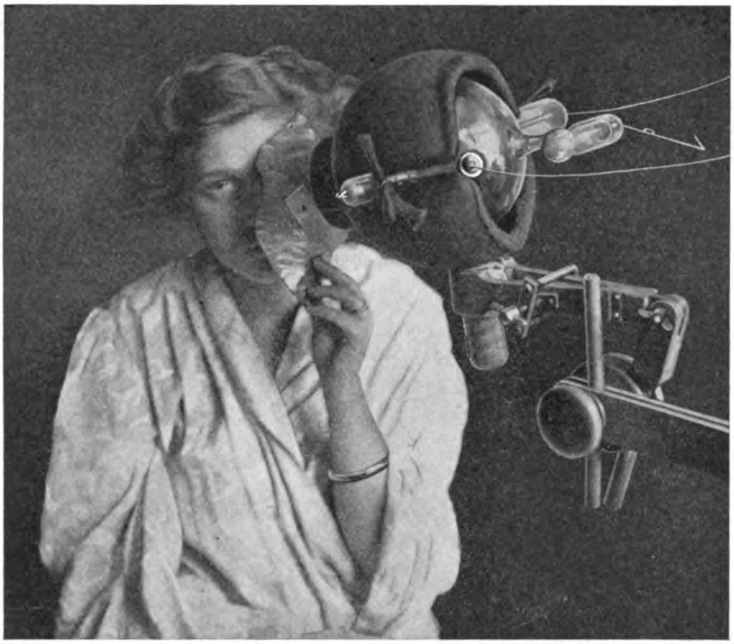

Fig. 754.—Technic of Röntgenotherapy for epithelioma of face. Tube in a localizing shield; perforated sheet of *x*-ray metal securely fastened to the surface by adhesive plaster.

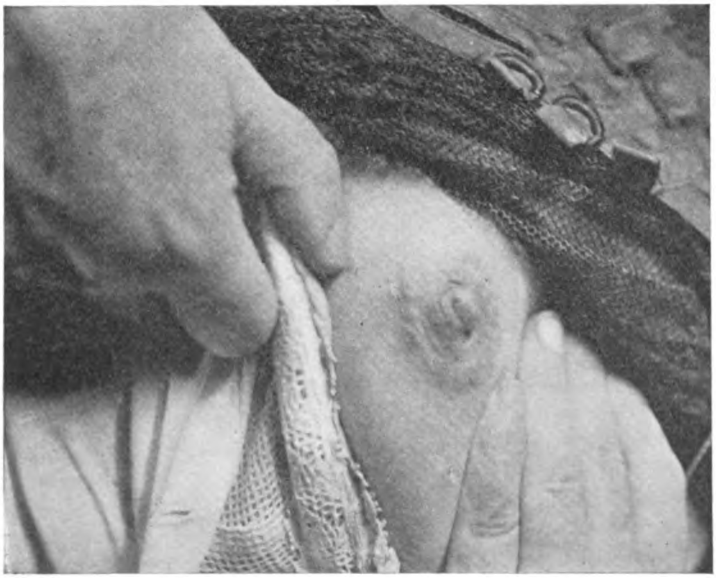

Fig. 755.—Epithelioma of nipple which had resisted radium treatment. Abandoned *x*-ray treatment after three applications.

a deep ulcer. The growth was freely movable and there was no pain, but merely an itching and uncomfortable sensation. There was a swelling and redness of the malar region. There were no glandular involvements or affection of the general health. The only treatment was by four applications of the x-ray each week from October 1, 1904, to March 1, 1905. For most of the applications a Morton treatment tube was used, which is made of lead-glass perfectly transparent to light, but opaque to the x-ray—this is the kind known as flint glass, and is the "paste" of which imitation diamonds are made. A piece of ordinary glass (transparent to the x-ray) forms the end of the prolongation through which the x-ray passes from the anticathode. When properly excited this tube is filled with a beautiful blue light, brighter in front than behind the equator formed by the plane of the anticathode. The ordinary "crown" or soda glass forming the end of the prolongation presents the familiar greenish fluorescence of the x-ray tube. With the fluoroscope a sharply defined circle of light is produced by the x-ray from this prolongation. It is covered with thin rubber and held directly in contact with the part to be treated. A liquid interrupter of either the Caldwell-Simon type or the Wehnelt was used with a 12-inch coil, with large self-induction in the primary coil, and a primary current of 4½ amperes, the resistance of the tube being 2 inches and the radiometer (Tousey's) 2. To avoid overheating the tube it was applied for a number of short exposures, aggregating from three to five minutes at each session. The tube was held in position by hand. The last month's

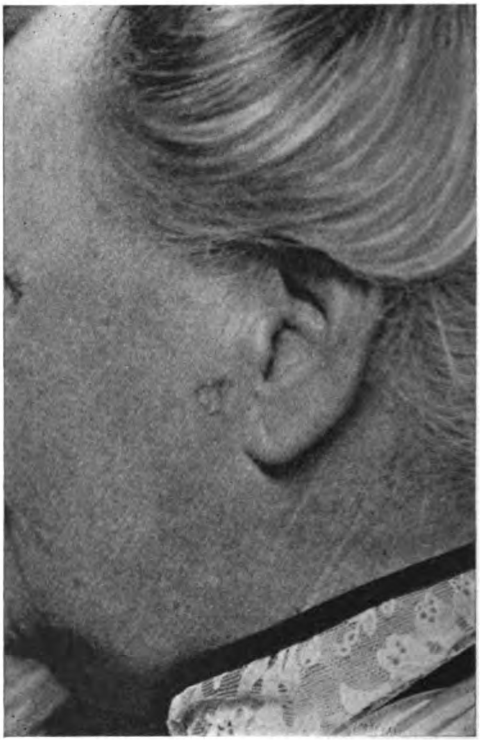

Fig. 756.—Epithelioma near lobe of ear. Had been unsuccessfully treated by radium and abandoned x-ray treatment after three applications.

treatment was with a Müller heavy anode tube, No. 13, and a localizing shield with a hard-rubber prolongation, the end of which (covered with thin rubber) was immediately in contact with the face. The anticathode was thus at a distance of 10 inches from the part to be treated. The resistance in the tube was 2 or 3 inches, the radiometer 3 or 4, and the duration of exposure six minutes, with the same primary current that was used with the Morton treatment tube.

Whenever a certain reaction, indicated by moderate redness and some itching, was established, the treatments were made somewhat weaker. The ulceration was completely healed in two months and a half, but the induration was more persistent and the treatment was not completed until the first of March, 1905. At that time the surface was flat and flexible; there was some redness as a result of the treatment. Three years after the cessation of treatment there had been no recurrence.


Fig. 757.—Epithelioma of nose, cured by *x*-ray treatment.

Several hundred similar cases have been treated in different parts of the world and with great success.

A Case of Epithelioma of the Gums and Hard Palate.—The patient shown in Fig. 758 had been seen by Dr. Brewer, who had removed a section for microscopic examination, and who considered the case as unsuitable for operation. She was seventy-five years old and had a positive family history of cancer. The trouble started four years before in consequence of irritation from a set of artificial teeth. When first treated, August 14, 1904, the upper gums and roof of the mouth and the inside of the cheek presented the appearance of a bright purple mulberry. Each little nodule was shiny and translucent. There was comparatively little pain. The treatment consisted in applications from a heavy target Gunde-


Fig. 758.—Epithelioma of gums and roof of mouth. Held in check for a long time by *x*-ray treatment, but finally fatal.

lach tube in a localizing shield with a cylinder 1¼ inches in diameter; the distance from the anticathode to the diseased surface being from 9 to 11 inches. An 8-inch induction-coil was used with a Caldwell interrupter and a primary current of 4 amperes. The resistance of the tube was equal to a 2½-inch spark-gap and the rays were No. 5 Benoist. Each part of the diseased tissue received an exposure of from fifty seconds to two minutes at each treatment, twice a week.

There was more pain after the treatment was begun than there had been before, but this disappeared as the case progressed.

A pathologic examination, made October 6, 1904, after two months' treatment, showed the same general type of epithelioma as in June, two months before treatment was begun, but more epithelial pearls and a mild acute inflammation, the whole tissue being infiltrated with pus-cells.

Six months' treatment kept the growth absolutely in check, but did not cause any part of it to disappear, made the patient more comfortable and better able to take all kinds of food except those requiring mastication. She had gained 2½ pounds in weight. She became discouraged by the expense of the treatment and of coming to the city from her country home, and thought perhaps that she would get along equally well without any further *x*-ray treatment. Reports during the ensuing year were to the effect that her mouth had gotten into terrible condition, and she died many months after the *x*-ray treatment was stopped.

Fig. 759.—Epithelioma of orbit. This patient has been under *x*-ray treatment several years, during which the disease has made slow progress.

Cancer of the Lip.—This is a type of epithelioma which is very different from that occurring upon other parts of the face; *x*-ray treatment should not be depended upon as the sole method of treatment, but will serve as a valuable adjunct to surgery. It will help to prevent recurrence after excision. In more than one still in the scaly not ulcerated stage the author has obtained a permanent cure by *x*-ray treatment alone.

Epithelioma of the Eyelid and at the Inner Canthus.—Another class of cases is shown in Fig. 759, a seventy-five-year-old patient at St. Bartholomew's Clinic, with a deeply ulcerating epithelioma of the lower eyelid; *x*-ray treatment was employed for a period of about a year and a half, but it did not succeed in healing the ulceration. In fact, this actually became gradually larger during the course of treatment. Had this been in a region where more vigorous treatment was permissible a cure would probably have been effected, although the patient's age and surroundings were unfavorable.

Another unfavorable class of cases was illustrated by a St. Bartholomew's patient with an ulceration on the side of the nose near the inner canthus. The surface was smooth and red and level with the surrounding skin. It was adherent to the underlying tissues and there was evidence of deep-seated involvement; *x*-ray treatment continued for about a year seemed to hold this in check, but did not result in a cure. Here again the patient was old and poor, and the region was one in which vigorous treatment was contraindicated.

In cases like the two last *x*-ray treatment is useful as a palliative means if an operation is impracticable, and also before and after operation as a means of preventing recurrence.

It is going to an extreme to say that *x*-ray treatment is not indicated in epithelioma where the skin has become adherent, but it is certainly true that there is a very much greater prospect of success where this is not the case.

Cancer of the Penis.—According to Robinson,[1] the *x*-ray has benefited or even cured certain cases, but in other cases he says it has hastened the growth, and its long-continued use for a course of twenty, thirty, forty, or even a greater number of treatments wastes time and may reduce the possibility of success from an operation.

There is no doubt that most cases of cancer of the penis should be promptly operated upon surgically. The *x*-ray used afterward and commenced even before cicatrization will greatly increase the patient's chance of escaping from recurrence. If, for any reason, it is desired to avoid an operation and try the *x*-ray as the sole treatment, the attempt should be given up if there is no evident improvement in three or four weeks' time. The testicles should be protected by sheet lead, and in most cases the entire penis and both groins should be exposed.

RADIOTHERAPY WITH THE TUBE IN DIRECT CONTACT WITH THE BODY

The theory that the *x*-ray itself does not cause radiodermatitis, but that the latter is due to a condenser effect, and may be avoided by placing the tube in contact with the surface, has found its principal adherent in Dr. Geyser. His records show a series of about 5000 applications with the tube in contact without a burn, but in a personal statement to the author Dr. Geyser says that he has had more than one burn due to the patient not holding the tube in perfect contact with the surface. His patients have sometimes made this mistake in order to lessen the feeling of static electric discharge which they experience, especially when the vacuum of the tube is a little higher than usual.

It should be noted, however, that these applications were with a small special tube, the Cornell tube (see p. 1109), and that the doses were small, and that there seem to have been no comparative experiments with the same doses to prove that they would have produced irritation if the tube had been at a distance. It is a fact also that Dr. Geyser does not apply large *x*-ray tubes to the surface, either for treatment (as in cases of leukemia) or for radiography, and that he does not produce burns. The same is true of other operators. For instance, in the author's service at St. Bartholomew's Clinic not a single burn has been produced from the discovery of the *x*-ray to the publication of this book, and the tube has been at a distance from the surface in most cases. The condenser theory supposes also that with the tube at a certain distance

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[1] New York Med. Jour., Dec. 29, 1906.

from the surface there is immunity from burns, but this again is to be viewed in the light of cases of leukemia, in which treatment begun by Dr. Geyser has been continued at the same distance by other operators, advised by him, and burns have been produced.

The author feels that the condenser theory of the origin of *x*-ray dermatitis has not been proved, but that it probably contains a certain element of truth. He believes it exceedingly dangerous to say that a burn cannot be produced with the tube in contact or with the tube at a certain distance ("far enough to avoid condenser effect"). He believes that correct dosage is just as important in this as in any other application of the *x*-ray. He hopes, however, that this method may prove a means of applying correct doses without the irritation which these have sometimes produced when applied from a distance.

TECHNIC OF DIRECT APPLICATIONS

The tube is of lead-glass, except at a window of soda-glass, where it is to be held against the surface.

Different tubes have been constructed for this purpose, beginning with Cossar's and followed by Morton's, Piffard's, Caldwell's, Tousey's, and, most recently, the Cornell tube. Most of these can be applied to the surface of the skin or introduced into the cavities or held near the surface. Then there should be mentioned the different unipolar tubes, from Tesla's tube to Stern's, all of which are intended for direct application.

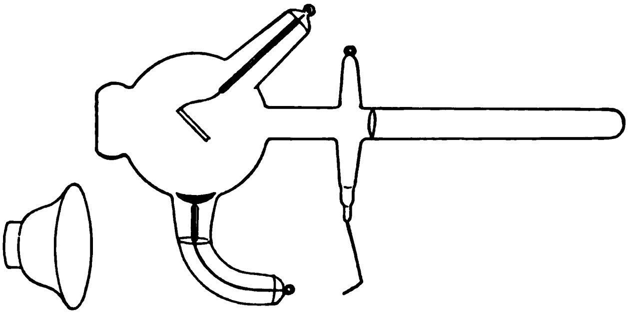

Fig. 760.—Tousey *x*-ray treatment tube. Electrodes turned back from the plane of contact with the flesh. Separate lead-glass shield for application to the gums. (Exhibited before the New York Odontological Society, Oct. 17, 1905; Dental Cosmos, June, 1906.)

Practically, the choice lies between Tousey's tube and the Cornell tube, which was made subsequently by the same manufacturers upon the same principles, but with slight variations, which the author thinks detract from its serviceability.

The Tousey *x*-Ray Treatment Tube (Fig. 760).—The bulb is of lead-glass except at the flat extremity of a short cylindric prolongation, where there is a window of soda-glass. The anode and cathode poles are both bent back so that there is no bare metal within 5 inches of the plane of the surface of contact or within 7 inches of the actual place of contact. There is a hollow glass handle, whose cavity does not communicate with that of the bulb. There is a regulator and a seal-off. The distinctive features of this tube, as compared with the Cornell tube, is that the Tousey tube has a bulb 4 inches in diameter and a heavy anticathode. These features fit it for standing heavy currents for a sufficient time for any ordinary radiograph, where as small an area of illumination as this will cover is sufficient. It holds its degree of vacuum better than the lighter Cornell tube. When employing the Tousey tube one is not confined to long, weak applications of five, six, or more minutes, but may make an application of the same amount of a ray in one or two minutes or less if desired. This tube may, therefore, be run with a Caldwell interrupter and other interrupters, with which we shall see the Cornell tube becomes overheated and loses its vacuum.

Dosage With the Tousey Treatment Tube in Contact with the Surface of the Body.—The anticathode is only 2½ inches or 10 cm. from the surface, and so, when the tube is directly in contact with the surface, the measurement of dosage by the Sarbouraud and Noiré tablets becomes a little different from the usual method. Ordinarily the test tablet is placed half as far from the anticathode as the surface to be treated, and on the principle of the square of the distance the skin is exposed to an intensity four times less than the test tablet. With the contact treatment tube, however, the test tablet and the skin are at the same distance and receive the same intensity of radiance. A sufficient exposure to produce tint *B* in the Sabouraud and Noiré radiometer indicates the absorption of about 5½ H. if the skin is twice as far away from the anticathode, but with the contact treatment the same change in the color of the tablet indicates four times the dose denoted ordinarily.

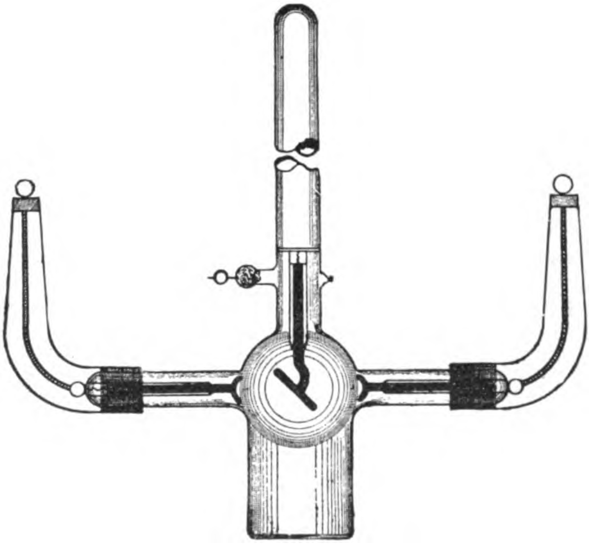
Fig. 761.—The Cornell treatment tube.

The Cornell Treatment Tube (Fig. 761).—This is a tube made for Dr. Geyser by the manufacturer of the Tousey treatment tube some time after the "Sinclair Tousey Tube," shown in Fig. 760. Dr. Geyser can scarcely lay claim to originality in the tube, for it copies all the essential features of the Tousey tube—the lead-glass bulb, the anticathode near the soda-glass window, glass prolongations insulating the electrodes, the turning of the latter away from the patient, and the insulated glass handle. The differences are lighter construction, contributing to easy handling, but detracting from ability to stand the current.

Dr. Geyser's originality lies in the routine use of the tube for contact treatments, with the claim that the same amount of *x*-ray will not produce a burn in this way, as if the tube were at some distance and a condenser effect were thereby established.

There are certain technical details which must be observed in the use of the Cornell tube. These are consequent upon the small size of the bulb and the lightness of the anticathode. Currents of the strength ordinarily employed in radiography or radiotherapy almost immediately cause the tube to break down. The anticathode becomes overheated and the vacuum falls below the useful limit. There are several ways in which this can be prevented and the tube kept in working order long enough for the therapeutic effect. If the Wehnelt interrupter is used, it is found desirable to expose a very great deal of the platinum point, so that a heavy current of 15 amperes will be allowed to flow, but with very slow interruptions. The rheostat may be used in securing this effect. Each of the slowly repeated impulses produces a flash of *x*-ray, and an application of about five minutes is required when the tube is excited in this way. Another method, which will usually be found preferable, is to use a mechanical interrupter, such as the Wappler interrupter, adjusted to give quite slow interruptions and a current of about 2 amperes. About five minutes' application is desirable in this case, but the quantity of *x*-ray bears such a direct relation to the number of interruptions per minute that even a very slight difference in the adjustment of the interrupter will necessitate a decided change in the duration of the exposure.

Any technic is suitable which enables the proper quantity of *x*-radiation to be applied without overheating the tube.

CARCINOMA

The cases in which *x*-ray treatment may produce a cure are practically limited to those of the breast and other external parts without internal glandular involvement, and the more nearly the tumor approaches in microscopic structure the border-line between a malignant and a benign growth, the greater is the prospect of complete success.

Effect of *x*-Ray Treatment in Cancer.—The mode of action of the *x*-ray in the treatment of cancer has been studied by Lyle.[1] He has always noted an abundant discharge after the applications, and this discharge is alkaline and crystallizes when exposed to the air. He regards this as an external evidence of a chemic effect, which accounts for the toxemic symptoms which sometimes follow an application. He thinks that this chemic product is dangerous and sometimes fatal, and that *x*-ray treatment should be limited to cases in which drainage can be established, and that it should not be used in deep-seated cancers.

Aprópos of this, the present author believes that substances analogous to toxins or antitoxins are produced by exposure of a cancer to the

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[1] Medical Record, July 15, 1905.

x-ray; that the production and absorption of these substances in large doses causes toxemic symptoms; but that in proper proportions they have a curative effect upon cancer. I have many times seen a beneficial effect upon cancerous involvements which from their position (as to depth or otherwise) could not have received enough radiation to produce a direct effect. It is true enough that a cancer which forms a flat, open, and freely discharging ulcer may properly receive larger doses of the *x*-ray than a malignant tumor without ulceration.

Perthes[1] has noted that the cancerous cells fuse into a uniform protoplasmic mass with an irregular outline and that their nuclei stain less and less well. Leukocytes and connective-tissue cells penetrate the mass; later the cancer cells are seen imprisoned and isolated in the meshes of connective tissue and undergo degeneration and absorption.

Ellis[2] thinks that the *x*-ray produces necrosis of both the parenchyma and the stroma of the tumor, accompanied by proliferation of elastic tissue and obliterative endarteritis.

According to Schwartz, the *x*-ray causes a decomposition of the lecithin, which is more abundant in rapidly growing cells, like those of neoplasms and like the normal parenchymatous cells of the testis, and in this way has a destructive effect upon these particular cells in doses which do not affect other healthy tissue cells.

The fact that serum from a part which has been strongly *x*-rayed may produce symptoms of an *x*-ray dermatitis if injected into a part of the same or another animal which has not been irradiated is suggestive of a chemic effect. It may be that an anticancerous serum could be injected deeply into the substance of a malignant tumor and produce a greater degree of benefit in the depths than the rays weakened by absorption in passing through the superficial parts of the tumor. This could be done without exposing the patient himself to the *x*-ray.

From the diversity of opinion among the above and many other authors it is evident that we do not know the exact way in which the *x*-ray affects the cancer cells, whether by a direct action or by an electrolytic process. There seems to be no doubt, however, that cancer cells have an especial susceptibility, and that under favorable circumstances they may undergo degeneration and absorption without ulceration or destruction of the mass of tissue making up the tumor.

Cases of cancer have died suddenly quite a long time after having been treated with a great deal of benefit by the *x*-ray.[3]

CARCINOMA OF THE BREAST

Fig. 762 is of a case of carcinoma of the male breast referred to the author by Dr. R. W. Hall. I operated upon the original growth in one breast, removing a tumor which the pathologic examination showed to be carcinoma, but with an appearance which did not indicate the greatest degree of malignancy. There was recurrence in the other breast within a year and *x*-ray treatment was at once begun. Mild applications were made three times a week until the development of a mild erythema, and then the treatment was kept up sufficiently to keep the skin slightly reddened. The tumor made no further headway from the

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[1] Thirty-second Congress of the German Surgical Society, Berlin, June 6, 1903.
[2] Am. Jour. Med. Sciences, January, 1903.
[3] Rosenberger, Second Röntgen Congress, 1905.

time that the *x*-ray was first employed, but there was no perceptible diminution in the size of the tumor for about nine months. Then it began to improve, and in two more months not a trace of it remained. The region of the original growth was *x*-rayed at the same time as the other, but never showed anything but a somewhat suspicious appearance. It is now five years since the cessation of treatment and there has been no return of the growth.

Fig. 762.—Recurrent carcinoma of the male breast cured (no recurrence in five years) by *x*-ray treatment.

Fig. 763 is of a patient referred, May 12, 1905, by Dr. Clement, Cleveland. The patient was a lady sixty-four years old upon whom the surgeon had five years previously performed an amputation of the breast, with removal of the pectoralis major and the axillary contents. The microscopic examination showed that the disease was carcinoma. There had been a recurrence in about two years which was considered inoperable, and for which *x*-ray treatment was applied for twelve months with a great deal of benefit. Some time had passed since then, and at the time she came to me there was a general cuirasse appearance of the breast and axilla and enormous swelling of the arm. Measurements

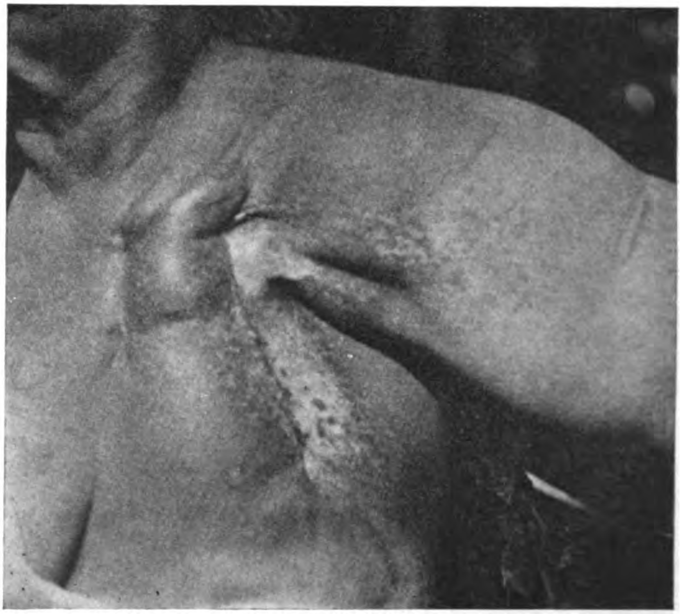

Fig. 763.—Inoperable recurrent carcinoma of breast held in check for three years by Röntgenotherapy.

made at this time showed an increase of 2 inches at the wrist, of 3½ inches in the forearm, of 2½ inches at the elbow, and of 2½ inches at the arm over the circumference of corresponding parts of the other arm. A fluoroscopic examination showed that there was no intrathoracic tumor.

This case never showed anything resembling a toxemic reaction from the *x*-ray applications.

An example of the technic employed is found in the following: Müller No. 13 tube, induction-coil 110-volt direct circuit, Wehnelt interrupter, 5 amperes primary and 3 ma. secondary current, resistance 2½ inches, radiometer No. 6, exposure five minutes at a distance of 12 inches from the anticathode, limited to an area 8 inches in diameter by a localizing shield with its 3-inch diaphragm. The exposures were sometimes divided, so that the axilla and the breast received exposures like the above separately.

High-frequency currents were applied to the arm, breast, axilla, and side of the neck from ultraviolet ray vacuum electrodes.

Treatments were given three times a week, except for a couple of months in the summer, and for two years the disease was held in check and the patient was well and happy and attending to her usual social duties. The disease in the meantime seemed to have lost its malignancy, There remained some fulness of tissue at the anterior fold of the axilla, but there was no longer any ulceration, and the arm was much less swollen. Then came a period of gradually increasing pain in the region of the other shoulder-blade. There also developed a small abrasion at the anterior fold of the axilla that was quite painful. The great swelling of the arm never returned, although some swelling continued throughout the entire course of the disease. While no local appearance of malignancy was apparent, it was evident that her general strength was failing, and the patient died in September, 1907. This was seven years after the operation, and for the last five years of her life *x*-ray treatment had kept her perfectly comfortable and an active member of society in spite of the presence of an inoperable carcinoma. There were a great many times when the patient forgot about the trouble, and really the only annoyance for months at a time was the swelling of the arm.

Another case was referred by Dr. Bissell. The patient was about forty years old, and had been operated upon two years previously for a carcinoma of the breast, which she had concealed until it was too late to hope for anything like a cure. The poor lady also concealed the fact of a recurrence in the other breast until it formed a large adherent mass and her general condition precluded operative treatment. There was also recurrence in the cicatrix on the side which had been operated on. The patient had a very strange vasoneurosis, which at the first inspection of the case and before the *x*-ray was turned on caused the entire chest to become a fiery red like the most violent blushing. The patient kept her face covered with a thick veil, so that one could not see whether the deep blush suffused the face also. At subsequent visits this blush gradually became less marked over the chest, and finally, when the patient became quite accustomed to the presence of the operator and nurse, it ceased to occur. At a subsequent period, however, another excellent surgeon, who was consulted in regard to a complicating pleurisy, saw a return of this vivid blush covering the entire chest. Knowing that the *x*-ray had been used the natural supposition was that the redness he saw was the first symptom of *x*-ray dermatitis; and from its extent and vividness the doctor thought that there was going to be a severe burn. This appearance, of course, was deceptive.

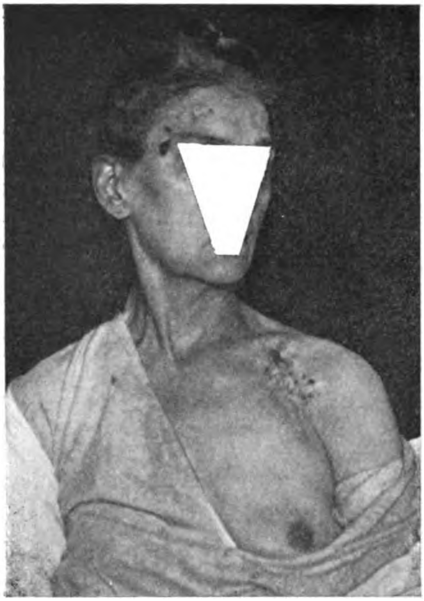

Fig. 764.—Epithelioma of the chest and face. Treated by another radiologist two years previously.

The treatments in this case were of the same kind as in the case previously described. The first treatment was followed by a febrile movement, 102° F., with some prostration. This was attributed to a temporary toxemia caused by the *x*-ray exposure. It did not occur again during the course of treatment.

This patient did wonderfully well for a time, the recurrent tumor in the breast diminishing one-half in size and the original cicatrix assuming a natural appearance. The patient's general health was greatly improved. Then came a complicating pleurisy, with effusion, and a rapid illness, which terminated fatally. It cannot be doubted that death was due to cancer, but the treatment gave wonderful benefit for a time in a desperate case. It looked at one time as if the disease might even be arrested for years, as in the case previously described.

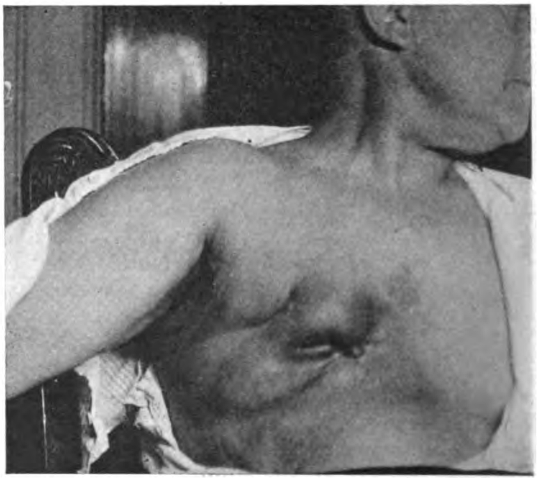

Fig. 765.—Inoperable carcinoma of the breast held in check for two and a half years by *x*-ray treatment. Case after two years' treatment.

Fig. 764 is of a patient who consulted the author about what she regarded as an unhealed burn from *x*-ray treatments by another operator

Fig. 766.—Inoperable carcinoma of breast held in check for two and a half years by Röntgenotherapy. Case a few weeks before death.

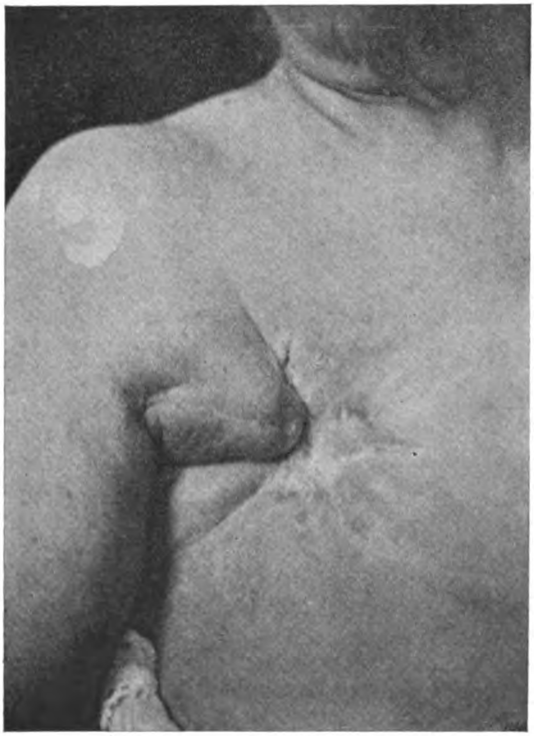

Fig. 767.—Recurrent and inoperable carcinoma of breast with enormous edema of the arm. Held in check for five years by *x*-ray treatment.

more than two years previously. These lesions are extremely painful and very slow to heal, though in the case referred to the carcinoma itself seemed to have been checked by the treatment. Ichthyol ointment and high-frequency currents applied from a glass vacuum electrode give more relief than anything else in such a case and also promote cicatrization.

In addition to the carcinoma of the breast, this patient had developed a flat epithelioma of the other side of the face.

The patient's daughter died of carcinoma of the breast.

Prognosis.—Cancer of the breast which has been operated upon and which has recurred gives excellent results at first, but after a certain period there may come a time when the disease gets beyond control. This may take a few months or several years, as in some of the author's cases. The *x*-ray appears to prevent the development of external growths or ulceration, and keeps the patient comfortable and for a time strong and well. The end, when it does come, is usually from internal involvement and often without definite symptoms. Scirrhous cancer of the breast in old persons presents a less unfavorable prognosis.

Fig. 768.—Inoperable recurrent carcinoma of breast. Held in check for a year by Röntgenotherapy.

RECURRENT CARCINOMA OF THE LARYNX

The patient, W. H., was a man of thirty-seven years, and was referred to the author in April, 1905, by Dr. Moore, of New Brunswick, N. J. The first symptoms of throat trouble developed in April, 1902. On April 17, 1904, he had undergone a complete excision of the larynx for carcinoma, and during that year had been breathing through the tracheotomy tube. In February, 1905, however, he became unable to swallow any food, either liquid or solid, in consequence of the return of the growth shutting off the esophagus. A gastrostomy was performed March 15, 1905, by Dr. Moore, and at about the same time the doctor wrote to me, making inquiry as to the probability of benefit from *x*-ray treatment after recovery from the shock of the operation. The reply was encouraging, and a few weeks after the operation had been performed the patient began making regular trips to my office for *x*-ray treatment. When I first saw him there was a considerable swelling in the neck, presenting almost the appearance of a new larynx, and above the tracheotomy opening, in the median line, was a discharging sinus, from which some of the liquids, milk, etc., which he tried to swallow escaped. The whole region was red and swollen, and presented the typic appearance of a recurrence of carcinoma. An *x*-ray picture which is reproduced herewith (Fig. 769) was made, and shows the presence of the hyoid bone and the absence of all the cartilages of the larynx, and demonstrates also very prettily the obliteration of the trachea below the level of the hyoid bone. The patient's weight at this time was 104½ pounds.

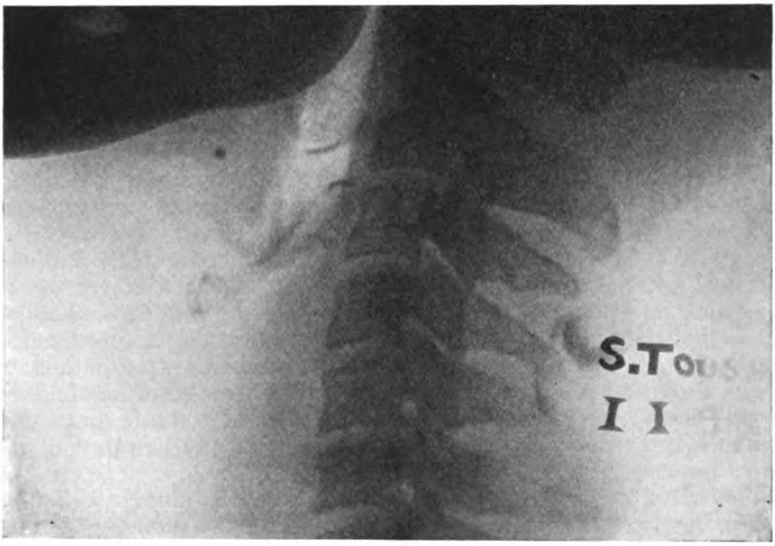

Fig. 769.—Case of laryngectomy and benefit from *x*-ray treatment for recurrent carcinoma requiring gastrotomy. Light area in front of upper vertebræ: patent part of pharynx and trachea.

The treatment consisted in the application once a week of the *x*-ray, allowed to shine above the front and sides of the neck. All of these applications were external, and followed a very distinct formula which the author has found successful in many cases of recurrent malignant tumors.

The *x*-ray tube has a tungsten anticathode and is about 7 inches in diameter, and has also an accessory anode. A little side tube, connecting with the main one, has means for lowering the degree of vacuum by sending a portion of the current through this regulator. The anticathode is a mass of copper, weighing ½ pound, with a button of tungsten electrically welded into the surface which faces obliquely toward the cathode. Tungsten has a melting-point twice as high as that of platinum. With a moderate strength of current this type of tube maintains its degree of vacuum longer than most other types. The metal does not liberate many particles of gas unless it becomes red-hot. The degree of vacuum for all of these exposures was measured in two different ways—one, by means of an apparatus for noting the resistance of the tube by measuring the equivalent spark-length at the *x*-ray coil, and the other, noting the degree of penetration of the ray given out by the tube. At the different treatments the spark length varied from 2½ up to 5 inches, and for one or two treatments even 7 inches, while the degree of penetration varied from 2 to 6 or even 8 units of the Benoist radiometer scale. The intensity of the ray is considered by the author as a very important matter, and was measured by a method original with him. The author's unit of intensity of the *x*-ray is such that $\frac{1}{60}$ Tousey will produce an erythema dose, or a Sabouraud and Noiré dose, or 5⅕ Holzknecht units in fifteen minutes at 13 inches from the anticathode to the skin.

Great intensity of the *x*-ray is analogous to great candle-power in an electric light and produces a photographic or therapeutic effect in a short time.

The Holzknecht unit of quantity is universally recognized, and a knowledge of the intensity or Tousey power of the source of *x*-radiance enables one to know beforehand how long an exposure at a given distance will be required to produce 1 Holzknecht unit. The method is described on page 1051. This is a method which can be applied quickly and easily to test the radiance of a new tube or a new strength of current and adjustment of apparatus, and enables one to determine beforehand the intensity of the radiance which is used, and in that way to decide on the length of exposure and the distance from the tube to the patient. It affords a method of dosage of the *x*-ray which the author has found invaluable in the treatment of cases and in deciding the safe limits of exposure to the *x*-ray when several radiographs of any one patient have had to be made.

The effect of treatment was to reëstablish the ability to swallow, though this always remained difficult, to materially increase the man's weight and strength, and to cause a great reduction in the cancerous swelling in the neck. This improvement continued for about a year, but did not save the man's life.

CANCER OF THE TONGUE

Guilleminot[1] reports 4 cases of carcinoma of the tongue unsuccessfully treated by the *x*-ray.

CANCER OF THE SHOULDER

A case of inoperable cancer of the shoulder has been reported as cured by *x*-ray applications.[2]

SECONDARY CARCINOMA OF THE MEDIASTINUM

Carcinomata of the mediastinum, secondary to cancer of the breast, have been treated with benefit in the direction of relieving symptoms

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[1] Congress of Electrology and Medical Radiology, Milan, September, 1906.

[2] Glim, Münch. Med. Woch., June 20, 1905.

and prolonging life. Pfahler[1] has published the histories of 6 such cases.

The object should be to use such a quality of ray and to have the tube at such a distance as will produce a deep effect without undue irritation of the skin. The anticathode of the *x*-ray tube should be about 10 inches from the surface and the penetration should be about No. 7 Benoist, but the proportion of soft rays reduced by the use of a 3 mm. aluminum filter. The benefit will probably be greater from frequently repeated mild exposures than from single severe ones. A dosage of ½ Holzknecht unit will usually be found correct. The cross-fire system, whereby the rays reaching the growth pass through different portions of skin each time, and especially always protecting the skin, which is not in a direct path toward the growth, add greatly to the efficacy of the treatment.

CARCINOMA OF STOMACH AND INTESTINES

We can seldom hope for more than a palliative effect in cancer of the stomach or intestines, but even here the treatment gives much relief from pain and adds much to the patient's strength.

A case treated by the author, in consultation with Dr. T. M. Lloyd, showed temporary relief from pain and from almost complete pyloric obstruction. He became able to retain food and had natural movements of the bowels. He died, however, in a few weeks from exhaustion. The disease was of long standing and of such an extent and the patient's condition so critical that no operation appeared justifiable, and the *x*-ray and the ultraviolet ray high-frequency applications were made with the hope of temporary relief only.

More recently the author has treated such cases at a somewhat earlier stage and with very great benefit. A screen of aluminum 3 mm. thick has been used and the anticathode placed at a distance of 10 inches from the skin..

CARCINOMA OF THE UTERUS

A patient was referred by Dr. Royle. She was a lady fifty years old, with a very large uterine fibroid which made her look as if in the last month of pregnancy. Carcinoma of the cervix had developed and she had undergone an operation under ether. The whole pelvis was found to be one solid mass of cancer, and so the operation was limited to the removal of a section large enough to examine microscopically. The pathologist reported carcinoma, and the probability seemed to be that the patient could live but a few weeks. Treatment by the *x*-ray was begun, however, the patient having to come in a carriage, assisted by her physician and her mother, husband, and nurse. There was an abundant and very offensive discharge and great pain over the ovarian and lumbar regions. The *x*-ray was applied partly over the abdomen and partly through a vaginal speculum. The distance from the anticathode to the abdominal wall was 13 inches and the rays were No. 7 and the exposures eight minutes. Otherwise the details were the same as in the case of cancer of the breast described on p. 1113. The same technic was used for the vaginal applications. The *x*-ray tube was a regular Müller No. 13, and localization was accomplished by covering the patient's buttocks and thighs with *x*-ray metal with a hole just large

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[1] American Medicine, Feb. 10, 1906.

enough for the speculum. (At the present writing the author makes vaginal applications in similar cases by the use of a localizing shield and one of the smallest cylinders connected with it.)

Vacuum electrodes from one pole of the *x*-ray coil were applied over the painful ovarian and lumbar regions at each treatment. The treatments were given three times a week, and in three months' time the uterine tumor had diminished about one-half in size, the discharge and odor and pain had ceased, and the patient was coming to the office alone, on foot, and generally carrying a box of fruit for some sick friend. After this time the treatment was continued occasionally by Dr. Royle, and the patient was active and apparently well for eight months more. Then she developed gastric symptoms and died in a few weeks, presumably from cancer, but without any of the pathognomonic symptoms of that disease.

Other cases treated by the author and other operators show that it is not unusual to have marked improvement as to hemorrhage, discharge, pain, odor, and general strength. It is practicable even to carry such a patient through pregnancy and to see a healthy child born, but the ultimate prognosis seems to be uniformly bad.

General Results in Carcinoma.—The preceding cases of carcinoma, some cured, but most treated with very great temporary benefit, but nevertheless dying in from six months to six years, are fair examples of what may be expected from *x*-ray treatment of this disease.

SARCOMA

Many cases of this disease are favorably influenced by *x*-ray applications and a few cases have perhaps been permanently cured. There is no particular form of the disease which is recognized by all observers as especially apt to be favorably influenced, and in no form is this treatment contraindicated. The general principle is the same as in the radiotherapy of other malignant diseases—the *x*-ray has a depressant effect upon every kind of tissue. The rapidly proliferating cells of neoplasms, like the normal cells of the testis and the ovary, are more susceptible to the influence of the *x*-ray than other cells. The *x*-ray is applied in doses from which the more susceptible tissue-cells cannot recover, but from which the neighboring sound tissue-cells do recover after a period of depression. Where small repeated doses are employed the quantity applied is such that the sound cells completely recover from the effect of one application before the next one is made, while the neoplastic cells, more decidedly affected, do not completely recover between applications and experience a cumulative effect. The operator arranges the strength and frequency of the applications with this end in view.

Holzknecht regards sarcoma as more easily influenced than epithelioma by the *x*-ray. Coley, who is not a radiologist, but who has had a large number of cases treated by the *x*-ray, believes that the mixed toxins of erysipelas and streptococcus are of great value in sarcoma. According to his conclusions, the antitoxic treatment, either alone or combined with the *x*-ray, gives better results than the *x*-ray alone. Most radiologists, on the other hand, employ the *x*-ray alone or in connection with surgical measures in the treatment of sarcoma.

A surgical operation should be performed at the earliest possible moment after the diagnosis has been made, providing the growth can be removed with a reasonable degree of completeness without danger to life and without too great mutilation.

The *x*-ray has been employed as a prophylactic before surgical treatment. The advantage to be derived is somewhat doubtful as compared with the benefit to be derived from an early operation. Still, if the case is not a threatening one, and if the patient's general condition is such that preliminary constitutional treatment by tonics and hygienic surroundings is required, *x*-ray treatment may be recommended during this preparatory treatment. The benefit sought is to reduce the size of the tumor and so make it susceptible of more complete removal, and especially to convert some of the lymphatic channels into fibrous cords and thus reduce the liability to the formation of metastases. These preliminary applications should include a generous area of tissue around the growth, and the doses had better be mild and frequently repeated.

Prophylactic applications after an operation are of undoubted value, and may be begun immediately after recovery from the effect of the operation. It is not necessary to wait for the wound to heal and the applications may be made through the dressings. The doses should be small and frequently repeated, and should be continued until about 7 H. have been applied in about three weeks. Then applications of 3 or 4 H. may be made every two weeks for two or three months. The quality of the ray, as represented by its degree of penetration, depends upon the depth at which the lesion is located. No. 5 to 7 Benoist is correct for the treatment of the cicatrix after an amputation of the breast, while rays No. 9 or 10 would be suitable for a case of sarcoma of the kidney. The use of a screen for soft rays is to be recommended in almost every case. The rays which it will arrest are those which would be absorbed by the skin, and by cutting them out we are enabled to make more effective applications to the deeper tissues without injury to the skin.

Fig. 770.—Sarcoma of the lower jaw. Improvement under *x*-ray treatment, but ultimate death.

TREATMENT OF AN INOPERABLE PRIMARY OR RECURRENT SARCOMA

What is said under the head of Melanosarcoma and in the earlier paragraphs on Sarcoma gives the author's views as to prognosis. The treatment is a little different, however, in the direction of being more severe. It should be as thorough as possible without causing ulceration. Either the method of large doses of about 7 H., repeated every two or three weeks, or that of smaller doses, 1 or 2 H., every two or three days, may be applied. The same differences between deep and superficial lesions call for differences in the degree of penetration and also for differences in the distance from the anticathode to the surface of the body. The latter distance may be as small as desired when the disease is practically on the surface of the body, but the distance from the anticathode to the surface of the body must be about 13 inches when the disease is deeply located. This is on account of the fact that the intensity of the radiance diminishes as the square of the distance increases. The distance from the anticathode to the skin should, therefore, be a large fraction of the distance from the anticathode to the disease, so as to make less relative difference between the two distances and less difference between the intensity at the two places. With the tube close to the surface the intensity at the skin may be four or six times as great there as at a deep-seated growth, and hence it would be impossible to produce sufficient effect upon a deep-seated growth without destroying the skin. This is without taking into account the fact that the deeper tissues receive a reduced strength of application in consequence of absorption by the superficial tissues. A localizer, such as the Ripperger shield, with a 4-inch diaphragm should be generally used to limit the action of the rays to the region of the disease.

Clopatt[1] reports the case of a woman, with probably malignant lymphosarcoma of the anterior mediastinum, successfully treated by fifty applications of the *x*-ray. Radiographs showed a reduction and finally the complete disappearance of the unnatural shadow cast by the growth, and there was a coincident disappearance of the dyspnea and other symptoms. It is not known whether the growth recurred.

Belot and Bissérie[2] have treated cases of diffuse sarcoma of the skin and of premycosis and mycosis fungoides by the *x*-ray. The last-named disease, although due to a germ infection, has many of the properties of cutaneous sarcoma, and the *x*-ray in massive doses of 5 to 7 Holzknecht units of rays No. 4 or 5 Benoist has effected a cure in the two or three cases in which it has been used. Scholtz uses even larger doses, intending to produce superficial necrosis, but this does not seem necessary. In the cases treated by Belot it happened that one or two small regions accidentally received a larger dose than 7 H., and the effect was less desirable than elsewhere.

A case of very malignant sarcoma, involving the soft tissues at the angle of the jaw, recurring after two operations, disappeared under *x*-ray treatment and had not returned a year later.[3]

No doubt exists in the author's mind of the occasional permanent curability of sarcoma, both of the bones and soft parts, by Röntgen ray treatment. This is also the experience of Skinner of New Haven, Pfahler of Philadelphia, and M. L. Dorn among others abroad.

MELANOSARCOMA

This disease usually responds favorably to *x*-ray treatment, and shows either an arrest of the morbid process or an almost complete disappearance of the visible lesions. Some cases which have been reported showed only a very temporary arrest, but in most cases the benefit was long continued. The ultimate result, it is to be feared, will be that the majority of cases cannot be permanently held in check. Mild, frequently repeated doses, without ever exciting an inflammatory reaction, have given good results in some cases, while a case treated by Bissérie, an ulcerated melanosarcoma of the nipple with axillary adenopathy, received an application of 9 H. of rays No. 4 or 5, repeated fifteen days later. There was an intense reaction, followed by

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[1] Deutsch. Med. Woch., July 20, 1905, p. 1150.

[2] Arch. d'Elect. med. exp. et cliniq., 12, 855, 1904.

[3] Pfahler, New York Med. Jour., Feb. 23, 1907, p. 379.

complete healing of the ulcer, and three months later there remained only a small non-ulcerated and painless tumor of the consistence of a lipoma.

The milder method is generally more suitable for non-ulcerated sarcomata and the severe applications for the ulcerated and more threatening cases.

Fig. 771.—Melanosarcoma of back, recurrent. Only one or two x-ray treatments; without much effect.

As in other cases of malignant disease, the application should generally be limited to the region immediately embracing the disease. Some constitutional effect is doubtless always produced by breaking down of malignant tissue under the influence of the x-ray, and the author believes that in many cases an antitoxic action is thus secured. Extensions of disease in regions not exposed to the x-ray or in consequence of their deep location receiving only a small fraction of the dose applied to surface lesions often receive marked benefit, which the author accounts for on the hypothesis given above. Cases may occur in which the same profound effect on the blood from which so much benefit occurs in leukemia may be sought in sarcoma. It may be obtained by applications over the spleen and the long bones.

Fig. 772.—Melanosarcoma of the groin. Same patient as Fig. 771.

The case of melanosarcoma of the back and groin shown in Figs. 771 and 772 was referred to the author by Dr. Elsberg. Rapid recurrence, both locally and in the inguinal glands, had taken place after operation. Two x-ray applications were made during a visit which the patient made to this city, and these did not produce any perceptible change in the course of the disease. The case is introduced merely for the purpose of describing the author's technic. The x-ray tube was a Müller No. 13 heavy anticathode tube 6 inches in diameter. It was enclosed in a Ripperger shield or wooden box lined with lead oxid. At a distance of 6½ inches from the anticathode there was an opening 6 inches in diameter, which was directed toward the part to be treated. The patient lay face down on the table, with the anticathode of the tube 13 inches from the surface of the back; an area 8 inches in diameter was, therefore, exposed to the x-ray. A 12-inch induction-coil was used with the 110-volt direct current and a Wehnelt interrupter, transmitting 6 amperes of primary current and sending 1 ma. of secondary current through the x-ray tube. The rays were No. 6 Benoist and of an intensity of $\frac{1}{60}$ Tousey. Each exposure lasted three minutes, and was equivalent to 1 Holzknecht unit. These applications were to have been made three times a week until a slight cutaneous reaction was established, and then reduced in strength or frequency so as to maintain a slight reaction.

A case of recurrent alveolar melanotic sarcoma of the neck seemed to be entirely cured by three months' x-ray treatment applied after the second operation. The wound had failed to heal and the growth was rapidly extending to the entire neck.[1]

MULTIPLE PIGMENTED SARCOMA

The x-ray affords some benefit in this fatal disease and is the only treatment that does so. The difference between this and melanosarcoma is in the arrangement of the cells and also in the fact that the pigment in melanosarcoma is largely melanin, and in this disease it is mostly hemosiderin. It usually first develops on the hands or feet and extends upward to involve vital organs.[2]

Secondary x-Rays from Silver in the Alimentary Canal.—Hernaman and Johnson[3] have found that there is a definite value to the secondary x-radiation from metallic silver in the alimentary canal for the treatment of malignant disease thereof.

FLUORESCENT MEDICINES IN CONNECTION WITH *X*-RAY THERAPY

Experiments by the author show that the various fluorescent media which have been given internally while the patient was exposed to the x-ray probably have no beneficial result, due to the luminosity excited. Some of them, like bisulphate of quinin, are excellent tonics in themselves, and this is not questioned at all, but the special claim has been made that these substances, circulating in the blood and in all the other tissues of the body, become fluorescent under the influence of the x-ray and generate light in the tissues and that this light has a beneficial effect upon cancerous tissues. The fact that so good a man as Wm. J. Morton advocates this method is sufficient to make it worthy of the most careful consideration.

The fluorescent medium recommended by Kemp for gastrodiaphany is: Quinin bisulphate, gr. x, in a glass of water, to which is added ♏iv of dilute phosphoric acid. After this has been swallowed a glass of plain water is also to be taken.

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[1] Dr. Edwin Walker, Medical Record, Nov. 8, 1902.

[2] Lieberthal, New York Med. Jour., June 23, 1906.

[3] Abstract, Amer. Quarterly of Roentgenology, March, 1912, p. 57.

This gives sufficient fluorescence when an electric lamp is introduced into the stomach to produce a visible luminous area indicating the size, shape, and position of the stomach. The experiment must be carried out in a dark room.

Fluorescin is more strongly fluorescent and is non-toxic in the strength of ⅛ to ¼ grain to the pint (gm. 0.07 or 0.14 per 500 cc.).

Fluorescin produces a medium for gastrodiaphany when prepared as follows:

Give the patient 8 oz. of water with ʒj of glycerin, gr. xv sodium bicarbonate, and gr. ⅛ fluorescin. This should be prepared one-half hour previously and exposed to sunlight.

Esculin is also an excellent non-toxic fluorescent substance.

Either of the three media described above will become luminous when ordinary light shines through them. This is due to a slowing of the rate of vibration in the waves of light in passing through the liquid, and each particle of liquid becomes in a certain sense a source of colored light nearer the red end of the spectrum than the light was originally. White light, seen by transmission through such a solution, may have one color, while by reflection it sometimes has quite a different color. Many fluorescent substances are dichroic in this way.

A striking example of the slowing effect upon vibrations of light by fluorescent substances is shown by a simple experiment:

The spectrum of the Cooper-Hewitt mercury vapor lamp is almost a pure violet, as seen in a spectroscope, but when a piece of cloth coated with a suitable fluorescent substance is held close to the lamp and the reflected light from the cloth is examined, two brilliant red lines are seen to spring into view.

Fluorescent substances become luminous and variously colored under the influence of the ultraviolet ray, which is itself of such rapid vibration as to be invisible.

They also behave in the same way under the influence of radium rays, themselves invisible.

They give the same phenomena under the influence of the *x*-ray as in the case of the barium platinocyanid screen, which is so universally used in fluoroscopic examinations.

NATURE OF THE RADIANCE FROM FLUORESCENT SUBSTANCES

The author's belief that the radiance from these substances consists practically entirely of ordinary visible light, and not of invisible ultraviolet rays, is based partly upon the following:

Experiment (by the author, Feb. 28, 1908).—A Machlett *x*-ray tube, giving rays No. 7 Benoist and of an intensity of No. 14 Tousey, was enclosed in a Ripperger shield with a 4-inch diaphragm in a perfectly dark room. A piece of Willemite, exposed directly to the radiance from the *x*-ray tube, showed the same green fluorescence that exposure to an ultraviolet ray lamp produces in it. It was much less brilliant, however, than it would have been in the latter case. Still, Willemite serves as a test for the presence of *x*-rays, just as it is used as a test for the rays from radium, none of which are those technically referred to as ultraviolet rays. Willemite fluoresces so brilliantly when exposed to the ultraviolet ray that its green coloration serves as a very delicate test for the presence of this radiation. Now a barium platinocyanid screen was placed with its fluorescent surface away from the *x*-ray tube.

The Willemite fluoresced with a green color when held in front of the barium platinocyanid in a line with the x-ray. The color disappeared, however, when the Willemite was held somewhat to one side of the opening in the diaphragm so as to be shielded from the x-rays, though near enought to the brilliantly fluorescent barium platinocyanid screen to receive whatever rays emanated from the latter. The result was a pale, dirty blue coloration of the Willemite, such as it shows when the light from an ultraviolet lamp has to pass through ordinary glass to reach it, and is in this way deprived of the ultraviolet ray. Interposing a piece of ordinary glass between the fluorescent screen and the Willemite did not lessen or change this appearance in any way.

The last part of the experiment seems to show that the radiance emitted by barium platinocyanid under the influence of the x-ray does not contain the x-ray or any of the rays characteristic of radioactive bodies, or the ultraviolet ray in sufficient amount to be demonstrable by so delicate a test as Willemite.

A strong solution of fluorescin (gr. j to oz. j) in a perfectly dark room fluoresces brilliantly when exposed to the x-ray from a tube entirely enclosed in black paper (experiment by the author Feb. 29, 1904), so that no visible light could reach the solution.

The proper solution for internal administration (experiment by the author March 4, 1904) consists of (1) gr. $\frac{1}{8}$ fluorescin in ʒj alcohol, (2) ℥ss glycerini, (3) ℥ss to j olive oil, (4) water, q. s. ad. 1 pint. Mix thoroughly at every stage. The above solution gives only a questionable fluorescence with the unshaded x-ray. The same solution fluoresces well with the light from an ultraviolet ray vacuum electrode. This solution really forms a very delicate test for ultraviolet rays. Since it shows only a doubtful fluorescence when exposed to the x-ray, it is evident that no appreciable generation of ultraviolet rays can take place in it when so exposed.

Even if the stomach were filled with this solution in a case of cancer of that organ, exposure to the x-ray could produce only trivial luminosity in the liquid and probably no ultraviolet rays. When we consider the hundred or more applications of an hour each from an ultraviolet lamp of 1000 or more candle-power required in the treatment of lupus or epithelioma, it seems impossible that the feeble radiance from the liquid in question, acting for only a few minutes, could produce any effect upon the cancer. The author has given a fluorescent solution of quinin in this way in a case of cancer of the stomach and could not see that it modified the effect of the x-ray in any way.

Another experiment by the author (March 12, 1904) consisted in partly removing the vegetable matter which filled the stomach of a dead rabbit and replacing it with a radio-active solution and then making a radiograph showing the stomach region. The x-ray tube was enveloped in black paper and the room was darkened. No fluorescence or gastrodiaphanous appearance was visible. The fluoroscope showed great translucency through the dilated stomach, and this same fact is shown in the radiograph. Another radiograph, made after the stomach has been emptied, shows a very great difference. Only a skilled anatomist could tell where the stomach is. The conclusion from this experiment is that a radio-active solution introduced into the stomach does not assist in radioscopy by any transillumination effect. Since the increased penetrability was attributed to the mass of vegetable matter in the stomach it is not probable that the radio-activity of the solution had anything to do with making the radiograph show the stomach more clearly.

INFLUENCE OF THE INJECTION OF PHOTODYNAMIC SUBSTANCES INTO THE TISSUES BEFORE *X*-RAY EXPOSURES

A solution of eosin 1:1000 has been injected into the tissues by Kothe,[1] who has found that verrugæ will disappear after an exposure to the *x*-ray too short to produce any effect upon other verrugæ which had not been injected. Similar results were obtained in treating lupus and in experiments upon rabbits.

RADIOTHERAPY IN INFECTIOUS DISEASES

SPECIFIC IMMUNITY

The development of toxemia under *x*-ray applications has led to the suggestion by A. W. Crane[2] that *x*-ray applications might be used to generate an antitoxin in the system of a patient suffering from an infectious disease. This has not been sufficiently experimented with to know whether it will prove efficient. Possible advantages are that the antitoxin (using the term in a broad rather than a strictly accurate sense) liberated is derived from the identical germs or morbid tissues which are present in the patient, and thus the harm which might come from an error in diagnosis and the use of the wrong specific antitoxin or serum by ordinary inoculation is avoided. The method does not at all suppose a direct bactericide action of the *x*-ray upon pathogenic microorganisms in living patients.

RÖNTGEN APPLICATIONS FOR PRODUCING STERILITY

Men may be rendered sterile without loss of desire or ability for coition. The reported cases in which this has been done were given applications sufficient to produce decided dermatitis without ulceration of the scrotum. The spermatozoa were still absent six months later.

Women may be purposely made sterile by exposure to the *x*-ray applied over the ovaries. The greater thickness of tissue to be penetrated makes this require more total exposure than is the case in men.

Ascarelli Attilio[3] reports the cure of a case of osteomalacia by inducing ovarian atrophy through *x*-ray applications.

Gauss[4] regards the attempt to produce sterility by the *x*-ray as dangerous, and when he attempts to produce abortion obtains a written promise from the patient to have an operative abortion performed if the *x*-ray fails. This is to prevent a possible lawsuit for the birth of a deformed child.

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[1] Deutsch. Med. Woch., Sept. 15, 1904.

[2] Am. Jour. of Medical Sciences, March, 1908.

[3] Bolletino della Societa Lancisiana di Roma, 1906.

[4] Quoted by A. Hamm, Therap. Monatshefte, xxvii, No. 7, July, 1913.

RADIUM

Radium is a new element, which is supposed to exist, but which has not yet been isolated. Several of its salts, especially the bromid and the sulphate, have been obtained in what is thought to be a pure state, and it is from the study of these that our knowledge of radium itself is derived.

It is classified as a metal of the alikaline earths, very similar to barium. Its atomic weight has been calculated to be about 226 times that of hydrogen. It is thus one of the heaviest metals. The other metals which are radio-active also have very high atomic weight. The atomic weight of polonium is 234; that of uranium is 240; while that of bismuth, which is radio-active from an admixture of polonium, is 208.

This very high atomic weight is thought to account in some way for the property of radio-activity possessed by these substances.

The spectrum of radium shows twelve distinctive lines, one of them in the ultraviolet region being particularly marked. Pure radium bromid colors the flame of a Bunsen burner carmine.

Such small amounts of radium salts have been produced and they are so expensive that the efforts of the chemist have been devoted to the means of obtaining them in a pure state rather than to a study of the various possible compounds and reactions of radium.

The bromid is the most active salt of radium, and occurs in the form of small white crystals, which are very soluble in water. It is hygroscopic, and exposed to the air will gradually absorb sufficient moisture to become liquefied.

Radium chlorid has the same properties, but is not so powerfully radio-active.

The sulphate and the carbonate are white powders and are insoluble in water. The sulphate is preferable for almost every purpose except for the intravenous or subcutaneous injection of a radium solution.

None of these radium salts are destroyed or dissipated even by a red heat, although their radio-activity is sometimes temporarily reduced. Radium, therefore, is less interesting from a chemic than from a physical standpoint. The complex phenomena known as radio-activity are what make radium interesting and valuable.

RADIO-ACTIVITY

Radio-active substances were discovered in 1896, shortly after Röntgen's discovery of the *x*-ray in 1895. Becquerel found that rays of a character somewhat similar to that of the *x*-ray were given off by the metal uranium.

Becquerel rays (named from their discoverer), or the rays from uranium, produce many of the effects of the *x*-ray. They affect a photographic plate, ionize gases, and this electrification is governed by the same laws as in the case of the *x*-ray. The Becquerel rays, however, are reflected, refracted, and polarized in the same manner as light, and must have about the same wave length. Glass has the same index of refraction for these rays as for ordinary light.

The *N*-Rays or Blondlot Rays.—They are given the name *N*-rays in honor of Nancy, France, where Blondlot is a professor. The sources from which they are generated are the ordinary luminous bodies, including the Crookes tube, the Welsbach and similar lights, the Nernst lamp, red-hot metals, and the sun; and also non-luminous bodies, including bodies in a state of stress, sonorous bodies, a magnetic field, Hertzian waves, liquefied gases, odorous substances, soluble ferments vegetable tissues, and the human body. They have very similar properties to those of ordinary light, and under favorable circumstances are believed to make the human body visibly luminous in an entirely dark room. It is only fair to add that many unprejudiced observers have found themselves unable to perceive this luminosity.

Discovery of Radium.—M. and Mme. Curie, of Paris, made a series of very delicate tests of the radio-activity of different specimens of uranium residue, and found that they differed very markedly in activity. The inference was drawn that some substance of greater radio-activity than that of uranium was present as an impurity. This substance, which, however, has not been completely isolated, is called polonium, from Poland, Madame Curie's native country.

The further investigation of radio-activity was carried on by the Curies, the line of investigation consisting in separating a mass of radio-active substance into two portions by chemic processes and testing the activity of each portion. The portion more highly radio-active is subjected to further chemic analysis, until finally a very small residue of very highly radio-active substance is obtained.

It was in this way that the discovery of radium was made. In its purest salts, the bromid, chlorid, and sulphate, its radio-activity is from 1,800,000 to 2,000,000 times that of uranium.

Metallic radium has been obtained by Mme. Curie and M. Dubierne through the distillation of an amalgam of mercury and radium previously obtained by electrolysis. Its atomic weight is a fraction less than 226.

Properties of Radio-active Substances.—They give out a radiation and some of them give an emanation, which both have peculiar properties. Taking radium as the radio-active substance of greatest importance, it is found that it generates heat in itself without any apparent chemic combination, and these are the only substances which are known to produce heat in this way without the application of any outside force. A specimen of radium, whether perfectly protected from the atmosphere or not, constantly maintains a temperature 2° or 3° C. higher than that of its surroundings. This heat, of course, radiates from the radium in all directions, as it would from any other substance with a temperature higher than its surroundings. Its evolution is continuous and perfectly uniform, and is not accompanied by any perceptible loss of weight. Calculations have shown that the entire radiation of heat from the sun is the same that would occur from a sphere of the same size containing 1 gm. of radium per cubic meter (15 gr. per cubic yard). This radiation of heat, however, is not the most important part of the peculiar property known as radio-activity.

Radium constantly maintains a negative electric state, and radio-active substances are the only ones which do become spontaneously charged with electricity. It has the property of charging substances with negative electricity, both those which are in contact with it and those at a distance. It also has the property of ionizing air or other gases and liquids.

The current of electricity generated by a surface of 2½ square centimeters of barium chlorid containing a great deal of radium and of a thickness of .2 centimeter is about $\frac{4}{1,000,000,000,000}$ ampere. This represents an amount of electric energy equal to about $\frac{1}{10,000,000}$ Watt.

Radium could never serve any practical purpose as a source of heat or electricity, the quantities of both being so very small in comparison with its cost.

The Radiation from Radium.—This consists of three distinct kinds of rays—the alpha, beta, and gamma rays—which have entirely different properties. The diagram shows the way in which these different rays are affected by the action of a magnet. The *alpha rays* are deviated to only a slight degree and away from the magnet. They are deflected in the same direction as the Canal Strahlen (Goldstein), or in the opposite direction from that in which cathode rays would be deviated.

The *beta rays* are deviated in the same direction as that in which cathode rays would be deviated—*i. e.*, toward the magnet—and are seen in the illustration to be brought around so as to impinge vertically upon the plane from which they start. Some of them are more deviable than others and strike the plane nearer to the radium than others.

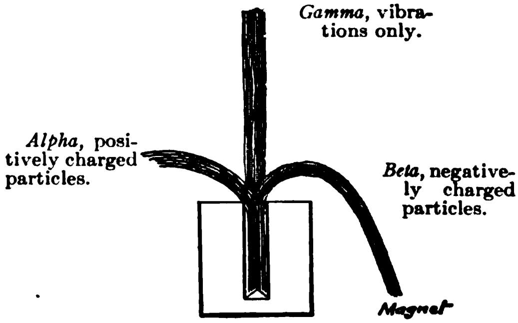

Fig. 773.—Separation of radium rays by a magnetic field.

The *gamma rays* are not deviated at all under the magnetic influence.

The radium in the illustration is supposed to be at the bottom of a deep cylindric hole in a heavy block of lead. Practically speaking, all the rays would emerge as a slightly divergent bundle of perfectly straight lines, but they are subjected to a sort of analysis by the selective action of the magnet upon the different kinds of rays that go to make up the whole radiation. The radium gives out this radiation in straight lines in every direction, but in the illustration the lead is supposed to be thick enough to absorb practically all the rays except those directed toward the opening.

None of the alpha, beta, or gamma rays are subject to refraction or reflection.

They all produce electric, chemic, photographic, and physiologic effects, and all penetrate substances opaque to ordinary light. The different kinds of rays, however, have these properties to very different degrees.

The **alpha rays** are believed to consist of particles of matter which, although almost incredibly small, are still quite large as compared with the particles that make up the beta rays. They travel at a speed of thousands of miles a second, but still at a slow rate as compared with the beta rays.

They carry an electric charge as great as the negative charge carried by the beta rays. As a result of the great size of the alpha particles compared with their velocity and their electric charge the alpha rays are but slightly deviated by a magnet. They travel to a distance of only about 3.5 cm. or $1\frac{4}{10}$ inches through the air from the radium from which they radiate and they penetrate only the thinnest metallic screens. They are practically all absorbed by a sheet of aluminum $\frac{1}{100}$ or $\frac{2}{100}$ mm. ($\frac{1}{2500}$ or $\frac{2}{2500}$ inch) thick, or by $\frac{1}{2}$ mm. of glass, the thickness of the wall of the smallest glass tubes in which powerful specimens of radium are sold. They have great similarity to the canal rays present behind the cathode of an *x*-ray tube. Chadwick, working in Rutherford's laboratory in the University of Manchester, has shown that alpha rays falling upon ordinary matter may produce gamma rays. Alpha rays constitute the greater part (64 per cent.) of the radiation from radium.

The **beta rays** consist of particles of matter calculated to be about $\frac{1}{1000}$ the size of a hydrogen atom, traveling at a velocity of 20,000 miles a second, carrying a charge of negative electricity, and being greatly deviated by a magnet in the same direction as the cathode rays in a Crookes tube. Some of the beta rays are more deviable than others in consequence of differences in their velocity. A piece of photographic paper laid along a line below the word *magnet* in the illustration would be affected along a band starting from the lead receptacle and extending outward for a considerable distance. The paths of the beta rays are bent by the action of a magnetic field of 2500 units, so that practically none of them can reach a distance of more than 70 mm. from the radium. They are very penetrating, but suffer a certain amount of absorption in passing through solid substances or the air, and those that get through are generally slowed. They produce a demonstrable effect at a distance of 2 or 3 meters or yards if not deflected by a magnet or absorbed by some solid screen. They constitute about 24 per cent. of the radiation from radium. They are very similar to the cathode particles in an *x*-ray tube whose impact gives rise to the Röntgen ray.

Only a small part of the beta rays are of a highly penetrating character and extend to a considerable distance through the air. They are arrested by thick sheets of metal. The distance at which they are effective is influenced partly by the absorption they undergo in passing through the air and partly by the fact that the intensity varies inversely as the square of the distance from the point from which the radiation takes place.

Absorption of Beta Rays by the Air.—There are hard and soft beta rays, and all gradations between these. Their absorption by air is at the rate of approximately 1 or 2 per cent. for each centimeter traversed.

Measurement of the Velocity of Beta Rays.—Becquerel's original method places the radium in a narrow, deep lead receptacle with a linear orifice. Above this, at some distance, is a diaphragm with a linear orifice at a right angle to the other. A magnetic field of a known strength causes different parts of the sheaf of beta rays to deviate more or less as evidenced by the action upon a photographic film placed beyond. The deviation indicates velocities of from 90,000 to 180,000 miles per second.

The beta particles have various initial velocities, slower ones being the more absorbable. They all undergo a reduction in velocity in passing through matter. W. Wilson[1] finds, for instance, that beta rays which start from radium with a velocity of 2.85×10^{-10} (*i. e.*, 10,000,000,000) cm. per second are slowed to 2.55×10^{-10} cm. per second by passing through 1.5 mm. of aluminum.

The *alpha* and *beta* rays are those which are chiefly effective therapeutically for surface work, and their properties, enumerated above, make it desirable that the radium should be directly in contact with the surface or only separated from it by the thinnest practicable covering.

Origin of Beta and Gamma Rays.—The atom of a radio-active substance consists of rings of negative electrons surrounded by a positive charge, but in an unstable condition, akin to a velocity of rotation such that centrifugal force exceeds cohesion. According to Rutherford,[2] there are two types of instability—the first leads to the expulsion of an alpha or positive particle, the second to the appearance of beta and gamma rays. A beta particle in escaping from the atom passes through the rings external to the one from which it springs, and at each ring it loses part of its energy in exciting one or several gamma rays.

The Gamma Rays.—These are not deflected by a magnet, but travel in straight divergent lines from the point from which they radiate. They are highly penetrating and are not entirely arrested by 2 or 3 cm. (about 1 inch) of lead or glass. They do not consist of material particles, but are of the same nature as the *x*-ray, and are, therefore, supposed to be a form of motion. Their velocity is the same as that of light. They are less active physiologically than the other radium rays, it being a general truth in regard to radiations that the effect occurs only where they are absorbed. They form 10 per cent. of the radiation from radium.

Some gamma rays are more penetrating than the most penetrating *x*-rays from a Crookes tube. Oudin[3] says that he has seen a glass tube containing .75 gm. of pure radium bromid in Curie's possession brilliantly illuminate a barium platinocyanid screen through a thick sheet of lead. There are all degress of penetration in these gamma rays.

Interesting Theories About Radium.—Frederick Soddy[4] considers the following as probably occurring in the evolution of the elements: Uranium changes into radium, radium into emanation and successive products, lead changes into silver, and these changes are spontaneous.

Radio-activity and the Internal Structures of the Earth.—An examination of a great many rocks and minerals shows a greater amount of radium than would be necessary to maintain the internal temperature of the earth if it contained that proportion all the way through. There cannot, therefore, be the same percentage of radium below a certain depth. This is *apropos* of Rutherford's observation that the earth contains enough radium to account for its internal heat. Rutherford examined many rocks and minerals (R. J. Strutt).

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[1] Proc. Royal Soc., 84, 1910, p. 141.
[2] Le Radium, 9, October, 1912, 337.
[3] Ibid., Sept., 1906.
[4] Congress of the British Association, 1906.

The Radiation from Different Radio-active Substances.—Radium gives out alpha, beta, and gamma rays; polonium gives out only alpha rays; actinium gives out alpha, beta, and probably gamma rays; uranium gives out alpha and beta rays; thorium gives out alpha and beta rays.

The Ionizing Effect of Radiation from Radio-active Substances.—The air in which radium is placed is ionized and becomes a conductor of electricity. This effect may be shown in two different ways: one, by charging an electroscope with static electricity and noting the fall of the divergent gold leaves as the electroscope becomes discharged; the other consists in measuring the electric current from a battery which will pass across an air space introduced in the circuit (Fig. 774).

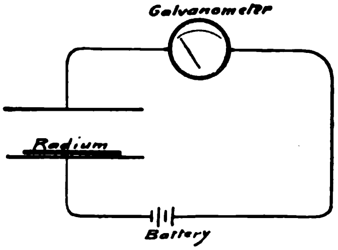

Fig. 774.—Simplest form of quantitative test of radio-activity.

The first method is very convenient for testing a substance for radio-activity and may serve even as a quantitative indication. The other method is the one adopted for the very delicate tests by which the radio-activity of radium is measured. A suitable arrangement of an electroscope for use in testing radio-activity consists of a metal cylinder with two windows, covered by wire gauze to prevent currents of air, but allowing observation of the interior. The electroscope itself is formed of a metal rod which projects through the top of the cylinder, where it is surrounded by a non-conducting collar. Parallel with its lower portion there is a strip of gold leaf which is free to diverge from it. The arrangement for charging the electroscope is a bent rod projecting through another insulated opening in the top, and which is normally held apart from the electroscope by the action of a spring.

A rod of amber or hard rubber is rubbed on silk or wool and touched to the outer end of the charging rod, which is held in contact with the electroscope and then released. The gold leaf becomes widely divergent, and under ordinary circumstances would remain so for a considerable length of time. The substance to be tested for radio-activity is placed in a tray, which is now applied at the bottom of the cylinder. The air in the cylinder becomes a conductor in consequence of an ionizing influence if the substance is radio-active. The static charge is carried by the air from the electroscope to the metallic wall of the cylinder and the gold leaf falls into contact with the vertical rod of the electroscope. The time that this requires furnishes a certain measure of the radio-activity of the substance. A telescope with a micrometer eyepiece may be used to measure the exact rapidity at which the gold leaf falls. A screen of any kind may be introduced above the radio-active substance, either for the purpose of testing the effect of various screens upon the radio-activity of the same substance, or as a means of reducing the radio-activity of a standard substance or of the substance to be tested.

Curie's Electrometric Apparatus for Measuring Radio-activity.—One pole of a storage-battery with a very constant potential is connected with the earth. The other pole is connected with a horizontal metallic plate. Above this is a second horizontal plate, separated from it by a small air space. This upper plate is connected with the earth through an electrometer and a quartz electric balance.

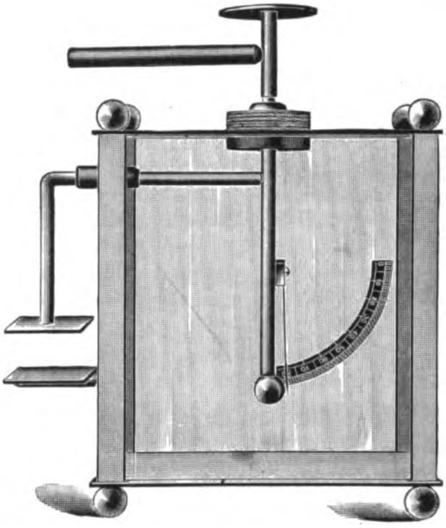

Fig. 775.—Piffard's electroscope. This may be used for testing radio-activity.

The action of the battery results in the lower horizontal plate being raised to a potential of a certain number of volts. The air between the two plates being a non-conductor, no current passes to the upper plate, and consequently the electrometer connected with that shows no deviation. Now a radio-active substance is placed upon the lower horizontal plate and the air between the two plates becomes a conductor of electricity. A complete circuit is, therefore, established from one pole of the battery to the lower plate, through the air to the upper plate, and through the electrometer and the earth to the other pole of the battery. The strength of the current, as indicated by the electrometer, shows the degree to which the air has been ionized and the radio-activity of the substance which is being tested.

For exceedingly weak currents the quartz electric balance is used to exactly counterbalance the electromotive force of the battery and to prevent the passage of any current through the electrometer.

Electromotive force generated by the quartz electric balance is susceptible of very delicate adjustment.

It is sometimes desirable to first establish a direct connection between the upper plate and the earth, which is broken after the electric current has begun to flow in a uniform manner.

Standard specimens of different radio-activity are required for comparison, and different screens may be used, or the specimens of radium may be placed at a measured distance from the two plates instead of directly between them.

The static electroscope is used chiefly to test various minerals for radio-activity. The apparatus in Fig. 775, made by Waite and Bartlett Co., is designed to detect a radio-activity of $\frac{1}{1000}$ that of uranium. Used without a magnifying glass it shows a radio-activity of $\frac{1}{10}$.

Current Electroscope of Zeleny.[1]—This is on the principle of a static electric pendulum. One terminal is charged to a potential of, say, 100 volts. A swinging sheet of gold foil is attracted to it and, receiving a charge, is repelled, but as it is connected with an ionizing space it loses its charge and is again attracted. The number of excursions per minute gives a measurement of the strength of the ionizing substance.

The electrometric instrument is the one used for testing the activity of different specimens of radium ranging from 1000 to 1,800,000 radio-activity.

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[1] Brochure published by Akademie, Gesellschaft, Leipsig, 1911.

The International Radium Standard.—The one adopted was presented to the International Commission by Madame Curie, and contains 22 mg. of pure radium bromid in a sealed glass tube almost completely filled.

Measurement of the Radio-activity of Specimens of Radium as Compared with a Standard Specimen.—Just as all the linear measures in a country are based upon a comparison with a carefully prepared and permanently preserved national standard meter or yard measure, E. Rutherford[1] thinks an international standard of radio-activity should be preserved. The standard specimen should be weighed and kept in a sealed glass tube of known size and thickness of walls.

The most reliable comparative measurement of radio-activities, which are very unequal, is by compensation. Two ionizing chambers are used, both connected with the electroscope in such a way that the current tends to pass through one and is opposed by the other ionizing chamber. Equal ionization in both chambers is indicated by an absence of current through the electroscope. In one chamber a plate of uranium oxid is used as a constant source of ionization. The first part of the measurement consists in measuring the distance at which the standard specimen of radium must be placed in order to exactly counterbalance the ionizing effect of the plate of uranium oxid. Then the same test is made with the radium under examination. The activities of the two specimens of radium are directly proportional to the square of the distance at which they will produce the same effect.

This measurement is based almost entirely upon the effect of gamma rays, and caution must be employed to detect the presence of mesothorium which might produce an equal strength of this radiation at a cheaper cost. This may be detected by dissolving the supposed radium salt in water and boiling for several hours to drive off all emanation. Examined immediately afterward, the radiation from radium will be free from gamma rays, while that from mesothorium will contain them abundantly.

A substance of very low radio-activity, like mineral waters, is tested by a comparison of its emanation with that from a standard solution containing, say, 10^{-10} grammes of radium to the cubic centimeter. This solution is perfectly stable, especially if a small amount of hydrochloric acid is added.

Radium Testing by Photographic Effect.—The author finds this excellent for practical therapeutic work.

The Tousey Unit of Power.—This is the photographic effect upon kodak film by 1 candle-power incandescent electric light with a carbon filament, and with the usual brightness or whiteness. One Tousey meter second is the effect produced by such a light at a distance of 1 meter from kodak film in one second. For actual measurement a portion of the film may be previously exposed to 1 Tousey meter second of incandescent electric light, and other portions are exposed to the specimen of radium, employing the conditions under which it is to be used. For example, one of the author's radium instruments is a small glass tube, containing approximately 20 milligrams of radium with an approximate activity of 2,000,000. This is placed close to the kodak film, sensitized surface up, but the film covered by two thicknesses of black paper. Different portions are exposed to the radium for various num-

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[1] Radium normalmasse und deren Verwendung bei radioaktiven Messungen, brochure published by Akademie, Gesellschaft, Liepsig, 1911.

bers of seconds, protecting every other part with heavy lead during each exposure. The entire film is developed in M. Q. developer of regular strength, for ten minutes, in complete darkness. The portion exposed to the radium for 5 seconds is as dense black as the portion exposed to 1 Tousey meter second of incandescent electric light. This specimen is of maximum power, and a contact application of the glass tube will produce a pronounced dermatitis after about five minutes, which naturally is about the time limit of its application until the period of cumulative effect, say two or three weeks, shall have elapsed. The same specimen of radium, tested in an aluminum treatment tube with walls ½ mm. thick would require longer application to equal 1 Tousey meter second, and could be applied for three times as long without producing an excessive reaction upon the skin; and since the radiation is of greater average penetration there would be a greater deep effect from this longer filtered irradiation. Lead screens are often added to secure still greater average penetration by arresting the beta and transmitting only the gamma rays, and the safety limit and effectiveness of the application may be measured in the same way.

A sheet of lead ⅜ mm. thick, and weighing an ounce to 12 square inches in addition to the glass tube and the aluminum treatment tube, increases the permissible time of exposure to 18 times that for the glass tube alone, or 6 times that for the glass and aluminum tubes combined.

Analysis of the Radiation from the Author's Radium Applicator No. 4 (20 milligrams, 2,000,000 Activity).—The bare radium salt would give rays in the proportion of—

Alpha	90 per cent.
Beta	9 per cent.
Gamma	1 per cent.
	100 per cent.

Enclosed in a glass tube of 0.3 mm. wall thickness, about 2 mm. diameter, all the alpha rays are absorbed in the salt and the glass walls, also 50 per cent. of the beta rays and 1 per cent. of the gamma rays; this leaves a ratio of—

Alpha	0 per cent.
Beta	82 per cent.
Gamma	18 per cent.
	100 per cent.

and this new total is composed of only about 55 per cent. of the original total radiation.

An additional screen of aluminum, ½ mm. thick, cuts down the beta rays about 50 per cent. and the gamma rays about 1 per cent., leaving the following ratio:

Alpha	0 per cent.
Beta	70 per cent.
Gamma	30 per cent.
	100 per cent.

The further addition of a lead screen, ⅜ mm. thickness, changes the ratio to—

Alpha	0 per cent.
Beta	12 per cent.
Gamma	88 per cent.
	100 per cent.

And 3 mm. of lead transmits practically nothing but gamma rays.

Applied to other specimens of radium, the object is first to measure the time of exposure required to produce 1 Tousey meter second effect upon kodak film. The radio-activity of the specimen may be calculated from a comparison of the exposure it requires to produce the same effect as the author's 20 milligrams of 2,000,000 radio-activity. The erythema dose and deep effect under different conditions as to filter may be calculated in the same way.

Radium Measurement by Sabouraud and Noire Pastilles of Barium Platinocyanid.—Such a specimen of pure radium salt in a glass tube changes a pastille to Tint *B* in about five hours, whereas five minutes contact produces an extreme erythema dose.

Electroscope and Ionization Chamber for Measuring Radio-activity.—The ionization chamber (*B*) of brass is about 11 cm. in diameter and 8½ cm. high. Through the top passes a thick amber spool insulating and supporting the electroscope *t*. The charging wire, shown separately, is passed through the hole in the amber spool and is withdrawn when the gold leaf is seen to diverge. Windows at opposite sides of the ionization chamber allow of observation through the microscope indicated by the dotted circle *m*. Screens of different materials and thickness may be introduced through the slit *E*. The stem *t* of the electroscope is a brass rod 1 mm. thick and 3 cm. long, the gold leaf having the same dimensions.

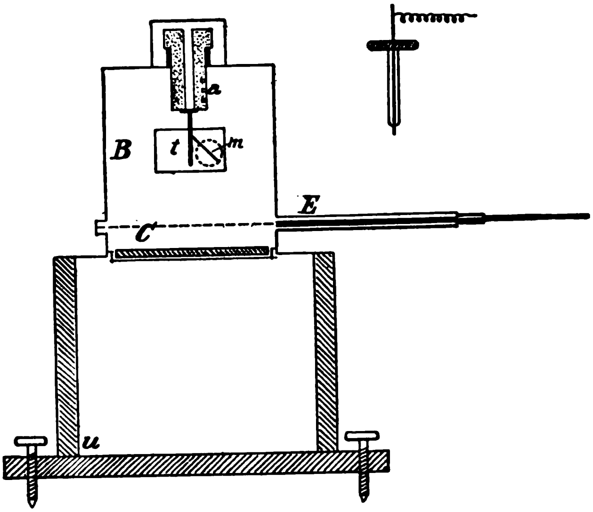

Fig. 776.—Electroscope and ionisation chamber for measuring radio-activity (Michiels).

ORIGIN AND COST OF RADIUM

Radium occurs in small quantities in many different minerals found in different parts of the world and also in the water of various mineral springs. For practical purposes it is extracted from pitchblende, a heavy black mineral, looking somewhat like anthracite coal, but breaking with a smooth fracture without jagged corners or edges. One of the principal deposits of pitchblende is at Joachimsthal in Bohemia. This mineral contains uranium oxid, which is extracted from it. The residue at a certain stage of this process contains the radium of the original mineral in quite a concentrated form, but still closely associated with a dozen or more other elements.

The treatment of a ton of this residue requires 5 tons of various chemicals and 50 tons of water. The product is about 1 gram (15 gr.) of pure radium bromid, with a radio-activity of 2,000,000.

From 500 tons of the ore (carnotite, etc.) 1 gram of radium is obtainable, a concentration of 100,000,000 is therefore required.

The price at which this was sold in 1909 was $80,000, or 400,000 francs, or £15,500, and the price has increased 50 per cent. in 1914.

Smaller quantities are sold at a corresponding fraction of the price per gram.

The best manufacturers prepare the less powerful specimens of radium bromid by taking a certain percentage of pure radium bromid and adding the necessary amount of barium bromid. The price is a corresponding percentage of that of the same quantity of pure radium bromid.

One decigram (1½ gr.) of pure radium bromid with an activity of 2,000,000 costs $12,000 in 1914.

One decigram of radium bromid of 180,000 activity (containing, therefore, 10 per cent. of pure radium bromid) costs $1200.

One decigram of radium bromid of 20,000 activity costs $120.

One gram (15 gr.) of radium bromid of a radio-activity of only 50 (*i. e.*, fifty times that of uranium) costs $6.

The other radium compounds—*e. g.*, the sulphate and the chlorid—are prepared in various strengths and sold at prices corresponding with the radio-activity of each specimen.

VARIATIONS IN THE RADIO-ACTIVITY OF RADIUM

The purest radium salt does not present any marked radio-activity when it is first extracted from the mineral containing it. The property develops in a short time if the radium salt is kept in a closed glass tube or similar air-tight container, and its full activity is developed in three or four weeks.

It is supposed that the development of radio-activity under these circumstances is due to the storing up of the emanation in the radium. The emanation, which is to be described in detail on a subsequent page, is a sort of vapor which arises from radium. It cannot pass through glass and passes only very slowly through a capillary tube. It renders radio-active any substance by which it is absorbed.

Radium which is enclosed in an air-tight container of metal, glass, or rubber, or if covered by varnish preserves its radio-activity unchanged for years at ordinary temperatures.

Exposure to the air does not cause any great loss of radio-activity in the case of radium salts which are in the solid state, but it does occasion a secondary loss if the radium salt is hygroscopic and absorbs enough moisture to be liquefied.

Effect of Temperature Changes.—Mme. Curie has found that radium loses 10 per cent. of its activity if kept at a temperature of 130° C. for an hour, but that a temperature of 400° C. for only ten minutes produces no noticeable effect. If maintained at a red heat for several hours a radium salt loses 70 or 80 per cent. of its activity. This radio-activity is regained gradually, and at the end of two months or so it is usually even greater than it was originally.

A red heat causes the emanation to almost completely disappear from a specimen of radium, and with it the property of inducing radio-activity in other substances. These may be at once completely restored by dissolving the radium salt in water and drying it at a temperature of 120° C. The salt may then have its full property of emanation, causing radio-activity in other substances even before it has fully regained its own radio-activity.

Effect of Solution.—*Dissolving a radium salt* causes the liquid to become radio-active, and this radio-activity is not all at once concentrated again in the radium when the solution is evaporated. The more dilute the solution and the longer the radium remains in solution, the greater amount of emanation is abstracted by the liquid and the less radio-active the radium salt is found when dried. If the solution has been exposed to the air for a number of days, much of the radio-activity of the solution is lost. After evaporation it is found that the dried salt is less radio-active than if the solution had been exposed to the air for a shorter time or had been kept in a sealed glass tube. It also takes a longer time for the radium salt to regain its original radio-activity.

Radio-activity seems to be due to the storing up of the emanation. The emanation is not very readily yielded up to solids, liquids, or gases by radium in the solid state, so that in this state it accumulates up to a certain maximum, which is maintained.

A solution of radium, on the other hand, very readily parts with its emanation, and, therefore, soon loses a large part of its radio-activity if exposed to the air. Such a solution regains its radio-activity if sealed up so that the emanation can no longer escape, but accumulates.

The Emanation from Radium.—The salts of radium produce constantly and uniformly a gaseous substance, which has already been referred to as the probable cause of the radio-activity of these substances and of the communication of radio-activity to other subtances.

This gas is also radio-active itself. It accumulates in solid radium salts and makes them highly radio-active. It is liberated, especially, from solutions of these salts unless the solutions are kept in sealed glass tubes, and it is rapidly liberated from the solid salts when these are kept at a red heat for about an hour. The first of these methods is the one which is used to obtain the emanation for practical therapeutic or experimental purposes.

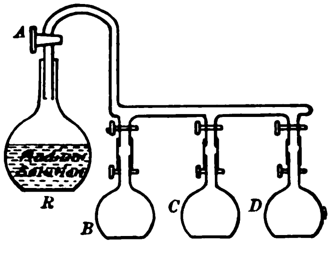

Fig. 777.—The dry radium salt may also be used to generate emanation.

Fig. 777 shows an apparatus for securing the emanation. At least 5 mg. of pure radium bromid dissolved in water is placed in a tube, *R*, which is connected at one upturned end with an aspirating tube. There is a plug of absorbent cotton in this tube at *A*, so that the air drawn through the apparatus contains only the gaseous emanation without possible small particles of the solution of radium. The apparatus includes a water bottle, through which the air enters. Being thus saturated with moisture, the air does not cause evaporation of the radium solution. Other parts of the apparatus are a simple aspirating syringe and tubes *B*, *C*, and *D*, which may be drawn full of air saturated with the emanation and preserved for use at any time.

Fig. 778 shows a type of apparatus for the preparation of radio-active liquids. One or two mg. of pure radium sulphate, which is insoluble, are placed in the open upturned end of the tube in the lower bottle of water. As fast as the radio-active solution is drawn off at the bottom of the lower bottle additional water enters from the upper bottle. The arrangement is such that no air can enter the lower bottle.

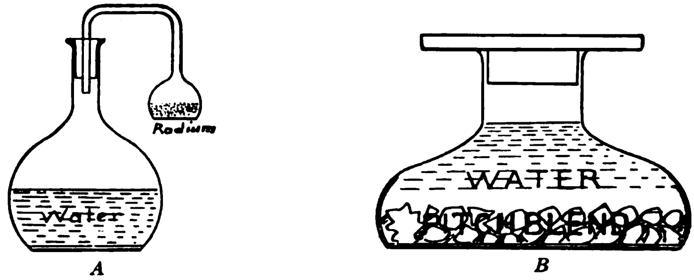

Fig. 778.—*A*, Preparing radio-active water by absorption of the emanation from radium; *B*, preparing radio-active water by immersing pitchblende.

Nature of the Emanation.—Niton, or the emanation from radium, has an atomic weight, according to different authorities—Curie, Rutherford, Debierne, and others—of from 176 to 235. The theory is that an atom of radium loses an atom of helium in order to produce an atom of emanation which, in its transformation, loses three more atoms of helium. Radium emanation is twenty times more absorbed by organic liquids like gasoline, alcohol, and benzene than by water.

Helium is spontaneously produced by radium at the rate of between 20 to 200 (probably 157) c.mm. a year per gram of radium. It is also produced by other substances which emit alpha rays.

It is very certain that helium is evolved from radium, and perhaps this is the essential part of the emanation. Helium is a gas lighter than hydrogen; it occurs abundantly in the sun, but only to a very small extent upon the earth. Of the twelve characteristic lines in the spectrum of radium, five are also common to helium.

The volume of emanation in equilibrium with 1 gram of radium is about 0.59 c.mm.[1]

The quantity of emanation is greatly reduced by the addition ot different acids and salts, such as sulphuric acid and barium sulphate to the solution of radium salt.[2]

Radio-active Emanation Contained in the Air Near the Earth.—This is derived from the uranium, radium, and thorium present in the earth, and its amount is such that a cubic meter of the air contains an

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[1] Danysz and Duane, Le Radium, 9, Dec., 1912, 417.

[2] A. S. Eve and D. McIntosh, Trans. Roy. Soc., Canada, 4, 1910, 67.

amount of emanation which would be in equilibrium with 80×10^{-12} gm. of radium. This is equivalent to 80×10^{-12} curies.

Radium Contained in the Atlantic and Ionization of the Air Over the Ocean.—Joly has found about 1.1×10^{-14} gm. of radium in 1 c.c. of sea-water. The air over the ocean receives an insignificant quantity of gamma rays and of emanation, but, nevertheless, has been found by various observers to have about the same conductivity and number of ions as the air over the earth. Eve[1] regards this anomaly as a serious objection to a purely radio-active theory for the normal ionization of the atmosphere.

Only the purest radium, thorium, and actinium salts give out an effective amount of emanation. Polonium and uranium do not produce an emanation.

Induced Radio-activity.—Any substance—solid, liquid, or gaseous—exposed to the direct influence of radium salts becomes itself radio-active, though this property is retained for only a short time. The conditions under which this occurs make it seem that it must be an effect of the absorption of the emanation.

The electric charge of the alpha rays emitted by 1 curie of emanation is about 90.8 electrostatic units per second.

A radio-active solution is not the same as a solution of radium (or a radiferous solution). The latter contains radium, which is constantly producing emanation, and in this way it either permanently maintains itself in a radio-active state or constantly induces radio-activity in other substances. A radio-active solution, on the other hand, may be simply a solution in which radio-activity has been induced by absorption of the emanation from radium. Its radio-activity disappears with the diffusion of this emanation. Radio-active solutions are prepared for immediate use. Radiferous substances—oil, glycerin, ointment, and medicines—on the other hand, may be kept for use at any time.

The strength of a radiferous substance is conveniently stated in terms of the number of micrograms of pure radium bromid contained in each gram of the substance. A microgram is one-millionth of a gram, or $\frac{1}{1000}$ milligram.

As will be seen later, there is reason to believe that the beneficial activity of certain medicines is enhanced by the addition of radium.

Other Electric Phenomena Connected with Radium.—More than once it has happened to Mme. Curie and others that radium that has been long kept in a sealed glass tube has developed a powerful static charge. On breaking open such a tube a discharge has occurred like that of a tiny Leyden jar and the precious particles of radium have been scattered over the floor. A slight electric shock is sometimes felt in the fingers under these circumstances.

Robert Abbe in such a case employed an ingenious device for locating the particles upon the carpet. He spread a sheet of sensitized paper over the floor and developed it after the proper time. The paper showed a chart of the position of the different particles of radium.

Mercanton,[2] in order to open a tube containing radium without danger of explosion, wrapped around it a platinum wire heated by

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[1] Le Radium, Feb., 1911, p. 64.

[2] Phys. Zeitschrift, No. 11, 1906.

electricity. A tiny invisible opening was made in the tube, as evidenced by the radio-activity induced in a neighboring piece of metal by the escaping emanation. A control experiment showed that the emanation does not escape in perceptible quantities from an unbroken glass tube. There was no protrusion of the glass at the point where a hole was fused in it, and the experimenter believed that in this particular case, at all events, there was a partial vacuum instead of an increased pressure inside the tube.

Absorption of Radium Rays.—The rays pass through a vacuum in very much the same way as through the air.

The alpha rays are practically all absorbed by 7 or even 3.5 cm. of air.

The radiation given out by a specimen of radium enclosed in a small glass tube produces an ionizing effect (in the apparatus for measuring radio-activity) which between 10 and 100 cm. varies inversely as the square of the distance.

Thus, in one of Mme. Curie's experiments, the current of saturation at 10, 30, 50, 60, and 100 cm. was 127, 174, 6.9, 4.7, and 1.65. A sheet of aluminum 0.01 mm. thick, placed almost in contact with a thin layer of thorium, transmits 38 per cent. of the original radiation. If radium is used, about 30 per cent. is transmitted, and from polonium or uranium, only 20 per cent.

The highly penetrating rays from radium become practically non-absorbable after passing through several centimeters of solid substance. The alpha rays, on the contrary, appear to be rendered more absorbable after passage through even a thin metallic screen, just as if they consisted of solid particles which lost some of their momentum.

Absorption of Gamma Rays by Gases and Light and Heavy Substances.—G. Chadwick,[1] experimenting with radium rays which have passed through 3 mm. of lead (allowing only gamma rays to pass), finds that liquid air, liquid hydrogen, and liquid carbonic acid gas absorb about 5 per cent. of the gamma rays per centimeter of the liquid traversed. Water, aluminum, wood, and other light substances absorb from 4½ to 5½ per cent. and lead about 9 per cent. of these rays per centimeter.

Comparison Between the Absorbability of Beta and Gamma Rays.—Half the beta rays are absorbed by ½ mm. and 90 per cent. by 4 cm. of lead, and with increasing thicknesses of lead these beta rays have about the same power as the gamma rays. The gamma rays show a 50 per cent. absorption by 12 mm. of lead, and from there on such a low rate of absorption that some may be demonstrated to pass through even 20 cm. of lead.

Generally speaking, harder gamma rays emerge than enter a metal with very high specific gravity, and softer with metals of very low specific gravity.

Polonium rays undergo a transformation in passing through aluminum which makes them less penetrating. M. Curie found that a screen of aluminum, 0.01 mm., and then one of brass, 0.005 mm., thick, transmitted 2½ times as much of the radiation as when the same screens were used in the other order, brass and then aluminum.

Secondary Rays from Radium.—These are similar to those produced by the *x*-rays and cathode rays from a Crookes tube. Lead, in particular, gives out these secondary rays in a manner corresponding to the fluorescence of other substances under ordinary light. The

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[1] Le Radium, 9, May, 1912, 200.

secondary rays have less penetration than primary rays, but have an equal photographic effect.

A lead filter, arresting the alpha and the more absorbable beta rays, gives out secondary rays which are absorbable and would have an undesirable surface effect during long application. They should be arrested by a covering of rubber or several thicknesses of gauze.

Secondary Gamma Rays.—These have the same heterogeneous wave-length as primary gamma rays. Their existence is easily proved by the fact that an electroscope behind a lead screen, 0.7 cm. thick, shows the presence of 10 per cent. more gamma rays than when the same lead screen is placed near the radium 56 cm. away from the electroscope. Florance[1] has measured the quantity of gamma rays emerging from a sheet of lead through which primary gamma rays emerge, but in a direction from which the original rays are excluded by heavy masses of lead. Studying the properties of these secondary rays, he has come to the conclusion that they are simply diffused primary gamma rays. They may be compared, therefore, to the rays of white light which pass in every direction from the further side of a sheet of paper held up before a light.

Secondary gamma rays produced by beta rays have been demonstrated especially by J. A. Gray.[2]

Delta Rays.—These are produced by any source of alpha rays, and are, at least in part, secondary radiations caused by the bombardment of the substance itself by the alpha particles. They are slowly traveling electrons.

Luminous Effects of Radium Rays.—Many substances are fluorescent under the influence of these rays and become visibly luminous in the dark as long as they are held very near the radium. Salts of barium are markedly fluorescent. All but the purest and most expensive radium salts contain a large admixture of barium salts and hence are luminous in the dark. Pure radium bromid is scarcely visible in the dark. A diamond held near a specimen of radium usually becomes luminous, and this property sometimes distinguishes the gem from imitations. Deviation of the beta rays by a magnetic field enables one to obtain distinct radiumgraphs by the gamma rays alone, the object being beyond the carrying distance of the alpha rays. A longer time, of course, is required.

A part of the disturbing beta rays is absorbed by zinc sulphid, and clearer pictures may be obtained by mixing the radium salt with a certain percentage of this substance.

Radiumgraphs of small animals do not show the bones, since the bones and flesh are about equally resistant to the penetrating rays.

Influence of the Thickness of the Layer of Radium.—The amount of radiation is greater from a moderately thick layer of a radium salt than from a very thin one. The alpha rays practically all radiate from the surface. Those from the deeper layers are mostly absorbed by the superficial layers. The beta rays penetrate more abundantly from the deeper layers and it is owing to them that a thick layer of radium is somewhat more effective than a very thin one. A layer of radium 0.4 mm. thick gives out only about one-quarter as much radiation as a layer 2 mm. thick. The percentage of beta rays is almost twice as great in the latter case.

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[1] Phil. Mag., 20, 1910.

[2] Proc. Roy. Society, 85, 1911, 131.

Radium Rays Lessen the Resistance of Selenium Cell.—This effect is produced more slowly than by ordinary light or by the *x*-ray.

CHEMIC EFFECTS OF RADIUM RAYS

Barium platinocyanid is gradually changed from its original apple-green color to a brownish yellow, and this is accompanied by a lessened degree of fluorescence, just as in the case of exposure to the *x*-ray. The Sabouraud and Noiré pastils for the dosage of the *x*-ray are slowly discolored by radium rays. A similar effect is produced upon the test objects in the Holzknecht chromoradiometer, and these are of practical use in standardizing the therapeutic dosage of radium radiation.

The impact of radium rays causes a number of chemic changes which ordinarily require some outside influence, such as a high temperature. Water is decomposed into oxygen and hydrogen. Ozone is produced from the oxygen of the air. Oxygen and hydrogen or oxygen and nitrogen enter into combination. The alpha rays are much more absorbable and are also much more active chemically than the beta and gamma rays. But in most experiments the alpha rays are arrested by the walls of the container. The effect is like the catalysis, by which we used to believe that a substance exerted a chemic action by its mere presence without undergoing any modification itself.

The penetrating rays of radium cause decomposition of sodium iodid, and Kailan has found[1] that a solution of such a substance in water which contains the ordinary amount of oxygen absorbed from the air is much more rapidly decomposed than when the water has been boiled to free it from oxygen.

Radium decomposes lecithin and fatty acids, and its effect upon the embryonic cells and upon leukocytes and upon tumor cells, all of which are rich in lecithin, is partly at least due to the decomposition of this substance.[2]

The *emanation from radium* decomposes uric acid and other purins, and produces much more soluble substances. Mésernitsky[3] finds that .029 gram of sodium monourate is completely decomposed in twelve days by 50 millicuries of emanation.

The glass tube in which a specimen of radium is kept for a long time becomes somewhat browned by a molecular change.

The Spinthariscope.—Crookes has devised a little instrument, consisting of a closed metal cylinder with a barium platinocyanid screen inside at one end and a magnifying lens at the other end. A small particle of radium is placed at the back of a metal disk fastened a short distance in front of the fluorescent screen. Rays from the radium cause brilliant fluorescence in the screen. This light is seen to consist of thousands of scintillating sparks, showing the impact of successive alpha and beta particles upon the different crystalline particles of the screen.

Fluorescent substances exposed to the emanation from radium become luminous. Solutions of radium-bearing salts are luminous.

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[1] Sitzb. Akad. Wiss. Wein., 120, 1911.

[2] P. Mésernitsky, Roussky, Vratch ix, 423, Nov. 20, 1910.

[3] Le Radium, 9, 4, April, 1912, 145.

RADIOGRAPHIC EFFECT OF RADIUM RAYS

All kinds of radium rays produce an effect upon a sensitized plate. One must enclose the radium or the photographic plate in some light-proof envelope in order to secure the effect of the radiation apart from that of ordinary light from the fluorescent radium salt. The rays will pass through substances opaque to ordinary light and produce radiographs, such as one of a coin and a key inside of a leather purse. Radiumgraphs are less sharply defined than pictures by means of an *x*-ray tube and take a very much longer time. A fairly good radiumgraph of a metallic object at a distance of 10 cm. may be obtained in four hours with six sealed glass tubes of phosphorescent zinc sulphid and barium and radium chlorid, activity 1000. The plate in this experiment is enclosed in five thicknesses of black paper. Specimens of greater radio-activity produce radiumgraphs in a somewhat shorter time—one hour at a distance of 20 cm. or one day at a distance of 1 meter. A pure radium salt of 2,000,000 activity and 20 mg. produces a good radiogram in one or two seconds when in contact with the black paper enclosing the film.

All the rays from radium affect a photographic film, and this effect may be used as a measure of the activity of the substance. Two specimens, examined under the same conditions as to distribution over the surface of the applicator, as to the nature and thickness of the material separating the radium from the photographic film and as to distance, should produce the same photographic effect in the same length of time if they are of the same strength; and if two specimens tested under the same conditions take a different length of time to reproduce an equal photographic effect, we may know that their radio-activities vary inversely as the times required.

The beta rays, like ordinary cathode rays, give rise to abundant secondary rays in passing through a solid substance, and these are widely diffused. This is the cause of the lack of distinctness in radiumgraphs.

The salts of radium themselves lose somewhat of their pure whiteness in the course of time, this probably being due to an effect upon the traces of sodium present as an impurity.

THE THEORY OF RADIO-ACTIVITY

The radium atom uniformly generates energy in some way which we can only guess at, and this energy is manifested in two ways—one, by radiation of rays, both charged and uncharged with electricity; and second, by conduction, *i. e.*, gradual transmission to surrounding bodies in a gaseous or liquid medium by the production of an emanation and induced radio-activity.

Alpha rays are charged with positive electricity.

Beta rays are cathode or negative particles freed from the radium by the loss of the positively charged alpha particles.

The beta rays give origin by their friction with the radium atoms to gamma rays, which are similar to the most penetrating kind of *x*-rays.

The portion of a radium atom which remains after the emission of the alpha and beta particles is transformed into the gas known as the emanation.

The emanation itself gives rise to induced alpha, beta, and gamma rays, and what remains is partly helium gas, which is a stable substance giving rise to no further phenomena, and partly a solid substance (radium *A*), which causes induced radio-activity and is transformed into radium *B*. Successive transformations finally result in radium *F*, which is the same as polonium, and a final stage results in the production of lead. Thorium undergoes similar transformations, the final stage of which is bismuth.

PHYSIOLOGIC EFFECTS OF RADIUM

The radiation from a sealed glass tube containing 0.2 gram of radium of 800,000 activity carried in the pocket of a flannel shirt for six hours produced an ulcer without any pain and which took over a month to heal. This had been preceded by an erythema which developed after a fifteen-day period of incubation. This accident was a personal experience of Becquerel. An accident of the same nature occurred to Mme. Curie; and M. Curie, Dr. Oudin, and M. Giesel have made experiments upon themselves and upon animals.

Ten hours' contact with radium of 5000 activity in a gutta-percha sac caused an erythema, followed in twenty days by ulceration taking four months to heal.

Two hours' contact with 0.3 gram of pure radium bromid, contained in thin celluloid, caused erythema and dermatitis with a raw weeping surface like that following a burn. Complete healing took three months and left a smooth cicatrix like that from a burn.

Plate 15 shows the result of an experiment upon my own forearm with my radium applicator No. 4, a sealed glass tube containing about 20 mg. of radium of an activity of about 2,000,000. One minute produced no visible effect; two, three, four, and five minutes produced a more and more pronounced redness and itching with some desquamation, but no blistering or ulceration. This reaction was preceded by a period of incubation lasting about two weeks.

The same powerful tube of radium enclosed in an aluminum treatment tube, ½ mm. thick and covered with rubber, produces a dry redness in fifteen minutes and blistering in twenty-five or thirty minutes, as in the treatment of keloid.

Working in the extraction and testing of radium exposes one's hands to the radiation and sometimes causes dermatitis of the fingers like that from which *x*-ray workers suffer.

Paul Besson[1] has suffered from slight bad effects after studying specimens of radium for a number of hours. After a week's incubation an attack of rhinitis developed with considerable pain, discharge, and desquamation.

He classifies the methods of applying radium by which the skin may be affected as follows:

A Single Strong Application.—This may be with a specimen of great radio-activity left on the surface for a few hours or one of less activity for many hours. The result is an acute radiodermatitis.

Strong but Divided Applications.—A high degree of radio-activity applied for a few minutes each day produces a slightly milder inflammatory and ulcerative effect than the same length of application at a single session.

Long and Weak Applications.—This method uses very weak radio-activities applied for a long time. Besson says that it does not lead

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[1] Le Radium et la Radio-activite, Gauthier-Villars, Paris, 1904.

PLATE 15

Radium dermatitis excited by from one- to five-minute applications of 20 milligrams of radium element in a sealed glass tube.

to accidental ulceration, and he believes that it will be the method adopted in the future.

Pissareff's classification of the *degrees of radiodermatitis* from applications of radium is quoted by Besson as follows:

First Degree.—There is a period of incubation lasting two or three weeks. Then the hairs become brittle and fall out. The skin is left perfectly smooth and may be slightly pigmented. The hair begins to grow again in two months and the skin regains its normal appearance.

Second Degree.—This is characterized by an erythema, pink at first, but later of a darker red. The tissues are infiltrated and there is some desquamation, but no ulceration. The epidermis is left a little thin and shiny, and this sometimes remains for a long time.

Third Degree.—There is an intense dark red erythema. The skin is thickened, and blisters form which exude serum and afterward pus. Some ulceration ensues which is sometimes quite painful. The hair-follicles are completely destroyed and the cicatrix is permanently pigmented.

Fourth Degree.—There is complete destruction of the skin with pain, which is often very severe and may radiate to a distance. A brown slough forms and there is a thick discharge. The slough does not separate easily and the ulcer is a deep one, which is very tedious in healing. The cicatrix has nodular borders and it is depressed and pigmented.

There is usually a period of incubation of from eight to twenty-one days after the application of radium. The more sensitive the skin the more susceptible it is to radium, and diseased areas react much more than the sound skin.

EFFECT ON MICRO-ORGANISMS

The bactericidal effect is probably due to the alpha rays alone. It has been shown to act upon cultures *in vitro* by Pfeiffer and Freidberger (typhoid fever and cholera); by Hoffmann (staphylococcus and anthrax). Caspari has shown its efficiency upon tubercle bacilli introduced into the anterior chamber of the eye and upon diphtheria bacilli introduced into the muscles. Injections of radio-active solutions prevented the infection of the animal by these inoculations.

The alpha rays have so little penetration that it may easily happen that only the bacteria in the superficial layers of the culture are destroyed, and that the deeper layers of a culture in a test-tube are not affected by the radiation from radium.

Infiltrating the culture with the emanation from radium would induce the liberation of alpha rays, as well as others in the substance itself, and should destroy bacteria throughout the culture.

Werner has shown that in cases of radiodermatitis the affected tissues are not susceptible to bacterial inoculation, and this may be due to induced radio-activity in the tissues.

Braunstein finds that bacteria cannot develop in air laden with radium emanation.

Goldberg finds that typhoid, anthrax, and colon bacilli are destroyed by the gaseous emanation.

Dorn, Bauman, Valentiner, Kalman, and a number of others have found that radium rays and radium emanation are bactericidal.

The minimum exposure to radium emanation required to markedly affect and also to kill cultures of Bacillus prodigiosus have been studied by Jansen.[1]

Radiations Tested in Experimental Tuberculosis of the Eye.—Radium and mesothorium radiations do not kill the bacilli, though they do have some attenuating effect. They have an effect on the tissues, chiefly the blood-vessels. Ultraviolet rays have very much more effect on the bacilli.[2]

Among the earliest observations are those of Askinass and Caspari, verified by Danysz.[3] A culture of Micrococcus prodigiosus upon agar-agar was not affected in one experiment by exposure to the radiation from a distance of 1 cm. and through a sheet of aluminum 0.10 mm. thick. The same radium salt, activity not stated, completely arrested the development of a culture with which it was directly in contact for from two to four hours. Cultures of anthrax have been destroyed in the same way (Danysz). The latter author and Besson believe that the radio-activity induced in the culture by the emanation from the radium as well as the direct radium rays were operative in this case.

The beneficial effect from radium applications in bacterial diseases—*e. g.*, those observed by Tizzoni and Bongiovanni—in hydrophobia cannot be attributed to a direct bactericidal effect, because the tissues of the patient would be destroyed by any radium application powerful enough to arrest the development of bacteria in them.

The effect of radium upon infective micro-organisms and infection of the tissues has been studied by R. Warner.[4] Two principal results follow from his researches: First, radium rays may destroy bacteria in certain cases, and in others modify them without developing in them properties favorable to immunization; second, the tissue cells which are destroyed by these rays are capable of producing bactericidal substances which are scarcely observed in ordinary autolytic processes.

EFFECT ON PLANTS

This varies according to the conditions of the experiment. Lilac and chestnut buds are hastened in their development by exposure to radium or radium emanation in November or December, but no perceptible effect occurs with an earlier or a later exposure.[5]

Beta rays from radium retard the germination of different grains in proportion to the penetrability of their outer layer and not to their chemic composition.[6]

Radium emanations greatly increase the growth and chlorophyl content in seeds and plants.[7]

EFFECT OF RADIUM ON TOXINS

Sulphate of radium, 20 micrograms per 20 c.c., left more than thirty days in contact with Ostrovsky's necrotuberculin reduces its activity. Tetanus antitoxin was unchanged and diphtheria toxin and Koch's bacilli were only slightly attenuated.[8]

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[1] Zeitschrift für Hygiene, lxvii, 135, 1910.

[2] Flemmings and Krusins, Deut. Med. Woch., August 31, 1911, 1600.

[3] Danysz (Pasteur Institute), Comptes Rendes, Feb. 16, 1903.

[4] Münch. Med. Woch., p. 1625, Aug. 22, 1905.

[5] W. Peddie, Phil. Mag., 22, 1911, 665.

[6] E. O. Congdon, Sitzungshrift, K. Akad. d. Wiss., Vienna, 120, 1911.

[7] Falta and Schwarz, Berlin. Klin. Woch., 605, April 3, 1911.

[8] Archives des Sciences biologiques de Saint-Petersbourg, xix, 274, Sept. 25, 1911.

EFFECT OF RADIUM UPON ANIMALS

The radiation destroys infusoria, the larvæ of insects, and the eggs of birds.

Animal ferments, such as pepsin and pancreatin, according to Bergell and Braunstein, have their activity somewhat increased, but, according to Richet, lactic fermentation is retarded.

The venom of snakes (cobra and viper) is destroyed by the radiation or the emanation from radium. That of the land salamander and the common toad is not destroyed.[1]

Emanations of radium do not affect the gaseous respiratory exchanges, the oxygen in the arterial and venous blood remain normal. The blood-pressure is lowered by a vasomotor effect.[2]

Small animals which have died after exposure to radium show congestion of the spinal cord and its membranes with submeningeal hemorrhages.

One effect upon the eye is an atrophic retinitis without change in the cornea or the other ocular media.

There are different degrees of susceptibility. The same application which causes ulceration in a guinea-pig will only stimulate the growth of hair in a rabbit.

Danysz found that moderate applications in the case of a mouse produced erythema, with loss of hair and a discharging surface, but no general disturbance.

Exposure to radium of very great activity caused convulsions, paralysis, and death in about ten days without surface lesions. The fatal effects are produced by the gamma rays and by the most penetrating part of the beta rays. This effect is analogous to that of the *x*-ray.

The central nervous system in the smallest animals is covered by only thin and almost transparent bones and soft tissues, through which radium rays may act.

In the human being, on the contrary, these vital organs are protected by tissues, through which practically none of the physiologically active rays of radium can penetrate. None of the resulting nervous symptoms occur in man from radium applications, although they are not so very unusual from exposure to the radiation from an *x*-ray tube.

Young animals are much more susceptible to the fatal effect of radium applications.

Heinecke has found the wall of the intestines in small animals destroyed through the intact abdominal wall. The lymphatic glands, the spleen, and the thymus gland atrophy after exposures which do not injure the skin. Heinecke and Selden find that radium has an effect like the *x*-ray in producing sterility in men and women as well as in animals.

Ten or fifteen minutes' application of very active radium is followed by development of an acute erythema in twenty-four or forty-eight hours. No experiments have yet been made with the alpha or beta rays separately to ascertain their physiologic effect, but a screen of sheet lead has been used in applying only the gamma rays. Such a therapeutic application may take a number of days.

Pigmentation from Radium Radiation.—One milligram of radium bromid applied for two to six hours to the shaved skin of a rabbit's

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[1] Phisalix, C. R. Soc. de Biol., lvii, p. 366, Feb. 25, 1905.

[2] Loewy and Plesch, Berlin. klin. Woch., 606, April 3, 1911.

ear produces an area of decolorization surrounded by a pigmented zone. The pigment is deposited in the depths of the epithelial layer and it is not deposited when an albino rabbit is used for this experiment.[1]

EFFECT OF RADIUM UPON THE EYE

It causes a sensation of light in the eye, which may be due to fluorescence of some of the ocular media. It has been used in mild applications for trachoma and other lesions. The reported cure of hydrophobia in rabbits by the application of radium to the eye[2] is very curious and is important enough to be described at length.

According to these authors, hydrophobia virus, which has been exposed to radium emanation for from four to thirty-six hours, changes to a powerful antitoxin. A drop of this injected into a rabbit's eye renders the animal immune to subdural inoculation with active hydrophobia virus. Rabbits already inoculated with hydrophobia, and presenting a rise of temperature and weakness of the posterior extremities, were cured, while control animals, which were not treated, got worse and died.

These cases were treated by the application of radium of 100,000 activity over the brain and spinal cord. The exposures were for six to twelve hours the first day, five to twelve hours the second day, and four hours on each of the six following days.

Birch-Hirschfeld[3] has left 20 mg. of radium bromid in a mica envelope upon the closed eyelid of a rabbit for two to six hours. Only the beta and gamma rays could penetrate to the eye itself. There was a period of incubation lasting seven to sixteen days, followed by conjunctivitis, iritis, and superficial or interstitial keratitis (inflammation of the cornea). There was inflammation of the eyelid with loss of hair and ulceration. There was often atrophy of the optic nerve. The walls of the blood-vessels were but slightly affected. The retina was decidedly affected and in the same way as by the *x*-ray, not as by the ultraviolet ray. The lesion was a degenerative one, chiefly of the ganglionic cells. The optic nerve atrophy was secondary to this. There was no inflammatory change in the retina or optic nerve.

Subjective troubles with the eyes have been noted after studying specimens of radium for too long a time. The eyeball should be protected by heavy metal or lead-glass shields when radium is applied to the eyelids in therapeutics.

Wichmann[4] has made experiments upon the absorption of radium by the skin and other tissues. The normal skin arrests two-thirds of the radiation, most of this being absorbed by the derma and very little by the epidermis and the subcutaneous fat. Abnormal tissues in general, such as lupus, cancer of the breast, and fibromyoma of the uterus, absorb from 50 to 100 per cent. more than adjacent healthy tissues. This may very probably be the cause of an apparently selective action of the rays upon morbid tissues. The greater part of the rays being quite absorbable, a special arrangement of metal or other screens is required to produce an effect upon the deep tissues without undue

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[1] J. O. W. Barratt, Quarterly Journal of Experimental Physiology, 111, 261, 1910.

[2] Tizzoni and Bongiovanni, Riforma Medica, July, 1905, p. 818.

[3] Archiv. f. Ophthalmologie, vol. lix, pp. 287–306; reviewed in Le Radium, Sept. 15, 1905.

[4] Deutsch. Med. Woch., March 29, 1906, p. 499.

action upon the skin. The screen is to arrest the absorbable rays while permitting the passage of the highly penetrating rays. Wichmann's experiments, including 13 microscopic examinations, do not confirm the usual statement that there is a primary effect upon the inner walls of the blood-vessels.

J. Schlacta[1] has experimentally studied the similarity previously reported by Werner between the effect from intradermal injections of lecithin and that from exposure to the radium rays or the *x*-ray. The conclusion may be drawn from his experiments that, while these injections will cause alopecia and ulceration just like that from the radiation, we do not yet know the precise nature of the chemic products generated in the tissues by the radiation.

EFFECT UPON ANIMALS DURING THE STAGE OF DEVELOPMENT AND GROWTH

Tissues or organisms of slow growth appear to have their growth retarded by exposure to radium rays, while those of rapid development are either destroyed or the growth is slowed or quickened, according to the nature of the different tissues.

PATHOLOGIC EFFECTS OF RADIUM

The changes in the skin appear to be analogous to those resulting from the *x*-ray; they require a longer application, but are more intense.

Slow degenerative changes take place in the cellular elements of the skin, especially the cells of the epidermis, and, to a less extent, the cells in the glands, blood-vessels, and muscles. Connective tissue is not so susceptible.

There is a secondary congestion and extravasation of serum and leukocytes. The lesions in the blood-vessels are chiefly responsible for the very slow healing when ulceration occurs.

THERAPEUTIC USES OF RADIUM

1. The mildest applications modify the nutrition of the tissues and stimulate the growth of hair and the activity of the glandular elements. They may be useful in cases of atrophy, atony, or ulcers of the skin, and in ophthalmologic and gynecologic cases.

2. A more or less destructive effect may be produced upon such affections as epithelioma, lupus, nevus (birth-mark), verruca (wart), keloid, and a variety of other localized conditions.

Administered internally, solutions of radium modify morbid conditions of the gastro-intestinal canal and other viscera and produce a systemic effect. The latter may act as an adjunct to other medication.

Inhalations of air laden with the emanation from radium have been used for an effect upon tubercular processes in the lungs and air-passages.

APPARATUS FOR THERAPEUTIC USE OF RADIUM

There are two forms of apparatus for applying the radiation from radium. In one the radium is placed in a shallow cavity and covered by a very thin screen of gutta-percha, aluminum, celluloid, or mica. In the other the radium is mixed with a suitable waterproof varnish and

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[1] Münch. Med. Woch., June 27, 1905.

fixed upon the surface of the instrument. The latter method has many advantages.

Danne's varnish transmits 60 per cent. of the radiation, while the thinnest kind of a screen transmits only 10 per cent. of the radiation, and even this does not include the alpha rays.

Radium Applicator with a Screen.—Fig. 779 shows the usual type of apparatus. The shallow cavity is either 5, 10, or 15 mm. in diameter, and is said to be filled with either 0.01, 0.05, or 0.1 gram of radium. The activity of the latter may be from 50,000 to 1,800,000, the cost of the instrument and radium varying accordingly from $25 to $8000.

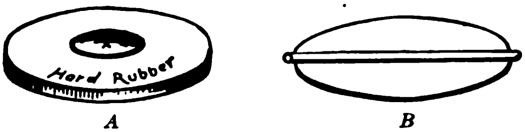

Fig. 779.—Radium applicators: *A*, *X*-radium cell covered by mica; *B*, radium applicator to fit on a rod.

The higher activities require only a few minutes' application, during which the patient may hold the instrument in position. The radium is usually held in contact with the surface to be treated, separated only by the thin screen of the apparatus. As it is difficult to thoroughly disinfect this after use, a better plan is to stretch the thinnest kind of rubber, not nearly the thickness of paper, over the entire instrument. This rubber may be renewed each time

The lower activities require long applications and the instrument had better be secured in position by adhesive plaster.

Fig. 780.—Hinged radium applicator.

Apparatus with Radium Secured by Varnish.—One type of instrument is shown in Fig. 779. The surface of a metal disk is from 10 to 25 mm. in diameter, and is coated with varnish containing from 0.01 to 0.06 gm. of radium of from 50,000 to 1,800,000 activity. The instrument and the radium cost from $25 to $5000. A little tube at the back of the disk serves to receive a rod acting as a handle or a cord by which the disk may be bound in position. The radium-coated surface is usually placed directly in contact with the part to be treated. It may be disinfected after use by washing in *water*, or *1 per cent. solution of potassium permanganate;* or *hydrogen peroxid*, or *1 per cent. sodium bisulphite* or *glycerin*, or *1 per cent. mercury bichlorid*. Exposure to formaldehyd fumes is an excellent method. Boiling in water for a few minutes does no harm, but *alcohol* and *ether* are to be avoided.

An ulcerated surface, whether malignant or not, had better be covered with aluminum foil, $\frac{1}{100}$ or $\frac{2}{100}$ mm. thick. This protects the instrument from contamination and arrests only an insignificant part of the radiation.

Other instruments are like those shown in Fig. 780, where the radium is varnished upon a thin piece of metal attached to a long stem with a joint, by means of which it may be adjusted in any position. This may be applied not only upon the surface of the body but also to many of the mucous membranes.

Others are metal cylinders coated with radium-varnish. These may be straight, curved, flexible, or jointed, for application to the eye, ear, nose, throat, urethra, or uterus.

Narrow strips of celluloid varnished with radium may be introduced into punctured wounds made in the subtance of a malignant tumor.

Radium-coated celluloid in flat surfaces or as bougies (Fig. 781) are chiefly employed by the author.

Radium-coated Cloth.—This is fastened upon the surface to be treated in cases requiring a long application. It contains 0.02 gm. of radium per square centimeter and of a radio-activity varying from 500 to 10,000. It costs from $1 to $6 per square centimeter. The surface is varnished and the cloth may be used any number of times.

Glass tubes containing radium are unsatisfactory for therapeutic purposes. The glass arrests a very large proportion of the rays and is liable to breakage.

Protection of the Neighboring Skin.—Sheet lead, 1 or 2 mm. thick, may be used when the application is to be severe. A hole of the proper size allows the rays to shine directly upon the diseased area, but the fact that the radium is at a little distance adds to the time of exposure.

Crusts, scabs, pus, or other secretions should be removed, as well as hard portions of epidermis. They would all tend to absorb the most active rays and reduce the therapeutic effect upon tissue cells.

Longer applications may be made upon ulcerated surfaces than upon unbroken skin.

THE DOSAGE OF RADIUM RADIATION

The quantity of a radium salt should be 1 or 2 cg. per square centimeter. The duration of an application depends upon the radio-activity and whether there is to be one application or a series of them. It must also be remembered that this is an agent of which some specimens sold for therapeutic use may not prove to be of specified radio-activity. The dosage given below is intended merely as a general guide, to be verified by cautious trial of each particular specimen of radium. No harm at all and only a trifling delay can result from too weak applications, while very great suffering may follow too strong ones.

Fig. 781. — Radium-coated celluloid rod.

A **radio-activity of 500,000** may be applied for an hour a day for six or eight days in order to produce a superficial destruction and an obliterating effect upon the blood-vessels in angeiomata.

Weaker specimens would have to be applied for a correspondingly greater length of time and stronger specimens for a correspondingly shorter time.

The intense destruction required in the case of commencing recurrence of carcinoma of the breast, when it is still quite localized, may be obtained by the application of radium of 500,000 activity for an hour a day for twelve or sixteen days. The same effect would be produced by the application of a specimen of 100,000 radio-activity for two or three hours a day for twenty or thirty days; or, on the other hand, three or four applications of six to ten hours each with an activity of 500,000 will produce this effect.

The mildly destructive effect required in lichen planus may be obtained by applications of a radio-activity of 500,000 for an hour each day for seven days.

Localized scaly prurigenous eczema is favorably modified without destruction of tissue by 500,000 radio-activity for two minutes three times a week, or 100,000 radio-activity could be applied once for half an hour.

Urethral or uterine applications of an activity of 500,000, lasting ten minutes and repeated three or four times, produce an alterative effect without destruction of tissue. An activity of 100,000 would require three or four applications of half an hour each.

Applications for intercostal and other neuralgias and for herpes zoster may be made with an activity of 500,000, applied for ten minutes at a time for four or five successive days.

Dosage of Radium in Medicinal Substances for Internal Administration.—Each gram of the medicine contains a measured amount of pure radium bromid, varying from $\frac{1}{2}$ to 10 micrograms ($\frac{1}{1000}$ mg.).

Radium drinking-water is beneficial in gout and rheumatism and effects a gradual reduction in blood-pressure. The usual dose is 1 microgram of radium dissolved in 1 ounce of water. This is about 2700 mache units.

Radium-bearing quinin is said to be more effective than plain quinin in the treatment of obstinate malarial conditions. It has the reputation of being beneficial in internal cancers.

A pill containing radium even in this very small amount will affect a photographic plate if left directly upon it for twenty-four hours.

Other medicines to which radium is added to increase their special effect as well as for its own properties are mercury, arsenic, digestive ferments, sodium nitrite, and various medicinal waters.

Intravenous Injection of Solution of Radium Salts.—One milligram of radium intravenously causes a very rapid fall of blood-pressure and death in a few hours. Cameron has noted a beneficial effect upon the blood-pressure and blood-picture from a single intravenous injection of 50 to 100 micrograms. He has not seen much effect in diabetes or chronic nephritis, but good results in chronic and subacute arthritis and myelitis. Three weeks after an intravenous injection, if death occurs, considerable radium may still be found in the bones and marrow.

Dosage of Radium in Mixtures for External Application.—Oleate of mercury and mercurial ointment may receive an admixture of 1 microgram of radium per gram. This is said to enhance the specific effect of the mercurial inunctions and dressings.

Radium ointment is made of lanolin or vaselin, or a mixture of both, and contains from 1 to 10 micrograms of radium bromid per gram. It has been used in carcinoma, epithelioma, and for rheumatic pain.

Radiferous glycerin is made by actually dissolving the radium bromid, while the ointments are mechanical mixtures containing solid particles of the radium salt. The emanation is given out very much more freely by radium in solution. This makes the solution more effective for the same percentage of radium. It must, of course, be kept in a sealed glass container when not in use. It has the same uses as the ointment, and is especially adapted for gynecologic application. It contains from $\frac{1}{20}$ to 10 micrograms of radium per gram.

Radiferous water may be prepared of any strength, from $\frac{1}{1000}$ to 100 micrograms per gram. A strength of from $\frac{1}{2}$ to 10 micrograms has been used as an injection in cancer cases. A strength of $\frac{1}{1000}$ microgram per gram may be used as a beverage and is more radio-active than the majority of natural mineral spring waters.

Radium-bearing plain water or mineral water preserves indefinitely the property of radio-activity, which in the natural radio-active spring waters is only an induced and very temporary quality.

Baths of Radium-bearing Water.—These may be prepared of greater strength than the natural radio-active spring waters and may be used at home as the radio-activity is permanent.

The Dosage of Radium in Terms of Holzknecht *x*-Ray Units.—Exposing a Holzknecht tablet to radium of 7000 activity through a thin metal screen, 5 H. are produced by twelve hours, and 10 H. by twenty-four hours' action.

An activity of 300,000 produces 5 H. in fifteen minutes and 10 H. in thirty minutes. Pure radium bromid, radio-activity 1,800,000, produces 5 H. in five minutes and 10 H. in ten minutes.

The total number of Holzknecht units from radium treatments over any given area should probably not be more than 6 H. for lupus or 10 H. for cancer.

The Holzknecht measurements are useful as a general guide, but are to be cautiously verified. Darier and others do this by self-experimentation. The specimen of radium is applied to different parts of the forearm, and the time required for the development of the reaction and its severity is noted.

Oudin has in his possession a specimen of radium of 1,500,000 activity, which takes an hour to produce 3 H., but which will produce an erythema lasting a month from a fifteen-minute application.

D. D. (Danlos ?) in Le Radium, Sept. 15, 1906, reports the use of a 1 cg. square of copper with 1 cg. of pure radium sulphate incorporated in a varnish. To test the dosage he applied this to different places on his forearm for from five seconds to fifteen minutes. A two-minute application was followed after a very variable period by a slight reddening of the skin. A ten-minute application led to an actual ulcer, requiring two or three months to disappear.

Dosage of the Emanation.—Inhalations of air laden with the emanation from radium should be prescribed with caution. Small animals which are allowed to breathe only air pretty well saturated with it die very quickly from its effects.

It seems to the author that the best method is that by which the emanation-laden air is very largely diluted with ordinary air. The ordinary screen radium-applicator may be used for this purpose, removing the protective sheet of metal, celluloid, or rubber, and applying a few drops of water to the exposed radium salt. The apparatus may be held within a couple of inches of the open mouth and nostrils. Only the greatest radio-activities give off sufficient emanation. The other form of apparatus for utilizing all the emanation (p. 1140) must be used with caution. Seventy milligrams of radium supplies enough emanation for the treatment of an entire roomful of people in an emanatorium.

Inhalations of the emanation may also be made by inhaling air, which has to bubble through a solution of thorium nitrate, but these are very weak, 1 mg. of radium giving out as much emanation as 20 pounds of thorium.

The *curie* is a quantity of emanation which is in electric equilibrium with 1 gram of radium. The practical unit of emanation either for inhalation or in solution is the microcurie or one-millionth of a curie.

The *mache unit*, formerly used, represents the electric energy in volt hours multiplied by 1000. A common dose of emanation is a liter of water containing 600 mache units, and this may be given several times a day. About 2500 mache units equal 1 microcurie. The number of mache units in a glass of water may be directly measured by a special electroscope called the fontactoscope.

Tubes of emanation (dosimetric) are sold. They are full of air as completely saturated as possible with the emanation from pure radium bromid.

A few minutes after subcutaneous injection of 5 or 10 cc. of water saturated with radium emanation the tissues of the entire body and even the breath are found to be radio-active. This extremely rapid diffusion does not take place in the case of oil saturated with the emanation, which, therefore, produces a stronger local effect.

Experiments (by the Author February 24, et seq., 1904) with a Solution Exposed to the Radiation from Radium.—The solution was made by immersing a sealed glass tube containing 0.1 gm. radium, activity 20,000, in a glass jar containing 6 oz. normal saline solution (0.6 per cent. NaCl) for fourteen days. The whole was kept in a small iron safe weighing 75 pounds. Tested in a variety of ways this solution seemed not to be radio-active.

The solution was not luminous in the dark.

It was not fluorescent when exposed to gaslight or the Cooper-Hewitt mercury vapor light, or the *x*-ray direct or shaded, or the ultraviolet ray.

It did not cause fluorescence in Willemite.

A piece of Willemite immersed in this solution glows as well as if in water, and almost as well as if not in a liquid, when exposed to the Cooper-Hewitt light (faint green crystalline glow) or to the *x*-ray, either direct or through a hand or a book (white glow), or to ultraviolet ray vacuum electrodes (brilliant green glow), or to the Görl ultraviolet ray lamp (very brilliant green glow, continuing as a white glow for five minutes after the light is turned off). In the last experiment the piece of Willemite held close to the eyes in the dark after the ultraviolet ray is turned off produces the sensation of a brilliant large white light. The difference is that the glow is whiter when the solution is used than without it.

The same solution, normal saline, exposed to the radiation from radium in another experiment by the author (Feb. 24, 1904) was mixed with an equal quantity of a solution of fluorescene, gr. $\frac{1}{8}$ to 1 pint. A thin transparent rubber bag filled with this solution was laid on top of two silver coins, under which was a kodak phot[illegible]ic film in bl[illegible] and orange envelopes. The whole arrangement was in a photographic dark room. No photographic impression was made upon the sensitized plate, though the experiment lasted eighteen hours. The same liquid could be seen to fluoresce brightly when exposed to daylight.

Experiments on the Physiologic Effect of Normal Saline Solution Exposed for Two Weeks to the Radiation from Radium (by Dr. R. C. Kemp at the Physiologic Laboratory of the College of Physicians and Surgeons with solutions prepared by the author).—*Experiment No. 1.*—March 5, 1904:

A cat weighing 2415 gm. received in the back a hypodermic injection of ⅘ ounce of the above solution.

A rabbit weighing 990 gm. received a similar injection, ½ ounce of the same solution.

Neither of these produced any local irritation, but there was slight temporary intestinal trouble in the cat.

Experiment No. 2.—March 11, 1904:

A dog weighing about 4000 gm. was etherized and the right carotid artery was opened and connected with a manometer which registered the blood-pressure upon a chart. The left femoral vein was incised, and at first 30 cc. of the above solution was injected. A few minutes later a larger amount of the solution was injected. The dog was not inconvenienced in any way at first, and was presented at a meeting of the Medical Association of the Greater City of New York a few evenings later. At that time he trotted around, wagging his tail, and apparently in perfect health, but he died a few days later, evidently in consequence of the operation, but just why it was difficult to say.

In both the experiments described above the only symptoms at the time of the injection were those directly attributable to the saline solution, such as an elevation of blood-pressure. There were none apparently referable to any radio-active property of the solution.

RADIUM THERAPY

This consists most commonly in the application of a radium preparation as directly as possible to a local lesion and leaving it in contact for minutes, hours, or days, according to the radio-activity employed and the extent of the tissue changes desired. The more filtering material is interposed to arrest the less penetrating rays, the longer the application may last and the greater is the deep effect secured.

RADIUM IN THE TREATMENT OF LUPUS

A radio-activity of 20,000 is applied for about twenty-four hours and causes ulceration, which heals slowly and leaves a cicatrix having a natural appearance and probably completely free from lupus. This is the ulcerative method as distinguished from the dry method.

The latter method seeks to modify the diseased area without destruction of tissue. Radium of an activity of 200,000, 300,000, or 1,800,000 (pure radium bromid) may be used in applications of from one or two to five or six minutes each day for several days.

A glass tube containing 20 mg. of a radium salt of 2,000,000 activity owned by the author can be applied five minutes only once in three weeks to any particular spot, but if filtered by ½ mm. of aluminum the application may be either three times as long or may be made once a week.

The results have not been so good in deep ulcerations from lupus or where the mucous membrane of the nose or mouth are involved.

Radium is applied especially to the nodules left after Röntgenotherapy, Finsen therapy, or other treatment, and which are often the site of recurrences.

RADIUM IN THE TREATMENT OF SKIN DISEASES

Verruca.—Young warts yield readily, but older ones may be resistant even if the horny layer is cut away. The exposure should be equal to four minutes with an activity of 1,800,000 and a weight of 10 or 20 mg.

Eczema.—Radium has not succeeded as well as the *x*-ray in eczema and prurigo. It is only to be recommended for small chronic and very circumscribed areas, especially about the hands and fingers, which have perhaps failed to respond to the *x*-ray. Oudin has cured an old case of pruritus ani by two ten-minute applications ten days apart. The radio-activity was 1,800,000, weight 25 mg., enclosed in glass and aluminum, allowing $\frac{1}{2000}$ of the total radiation to reach the skin. This fraction consisted practically entirely of gamma rays. Another method is to use a sheet of celluloid varnished with a reduced radio-activity and separated from the skin by paraffin paper and held in place for some hours, or until the appearance of a slight reaction, by strips of adhesive plaster; recurrences are prevented in this way.

Psoriasis.—As to psoriasis, radium therapy is indicated for patches upon the face and about the nails.

According to Rehns, a two- or three-minute application of 1,800,000 radio-activity to a patch of psoriasis causes reddening followed by disappearance of the spot.

The results so far have not been gratifying in *sycosis* (but Blaschko reports 3 cures out of 6 cases), *acne, impetigo,* or *hypertrichosis.*

Pigmentary nevi require an ulcerative effect, but *vascular nevi* do not. An application producing a mild erythema is sufficient to cause the obliteration of the small blood-vessels causing this deformity.

Alopecia does not yield to radium treatment.

Keloid sometimes yields excellent results and, in the author's experience, requires strong applications, say 20 mg. of 2,000,000 activity, filtered through the $\frac{8}{10}$ mm. glass wall of the tube (arresting all the alpha and the softest beta rays), and aluminum $\frac{1}{2}$ mm. thick, permitting the passage of all the gamma rays and the hardest beta rays. The whole should be covered with rubber to stop the soft secondary rays. Each part of the keloid requires an application of twenty minutes or somewhat longer.

Lichen ruber, rebellious *acne rosacea,* and **lupus erythematosus** sometimes yield to radium treatment.

Radium Applications for Chronic Arthritis.—Chronic arthritis may be favorably influenced by applications of an activity of 100,000 over different parts of the synovial membrane of the joint and the sheaths of the tendons. The alpha rays and the more absorbable of the beta rays are absorbed by a sheet of rubber $\frac{1}{8}$ mm. thick. The secondary rays which arise from this are diffuse rays of slight penetration, and to prevent their reaching the skin an additional covering of thin paper is used. A disk 6 cm. in diameter, coated with 0.10 gm. of radium of 100,000 activity, is applied for two hours over each of four different places about the joints on the same day. The same applications are made over other areas on the following day, and still a third series of four applications is made over other areas on the succeeding day. Two of these applications over the same areas would cause only a slight erythema without any bad result. Wickham and Degrais have shown the increased benefit derived from applications of very great strength through lead ½ inch or more thick and lasting forty-eight hours.

MALIGNANT DISEASE

Robert Abbe, of New York, has published the case of a child with apparent sarcoma of the jaw cured by radium. This is about the only supposed case of truly malignant disease which has been cured. Weaker and longer applications appear to be the best in cancer cases.

C. Esdra[1] reports the cure of an endothelioma of the face by applications of radium bromid—3 mg. were used thirty-five times, for an average duration of thirty to forty minutes each time.

Epithelioma.—All forms of "benign" superficial epithelioma—ulcerative, papular, or exuberant—are cured by comparatively mild applications of radium. Malignant epitheliomata, like those of the lip and tongue, are benefited, but so far have not been cured by radium, and the same is true of carcinoma.

A. Blaschko[2] finds that there are some recurrences after "cure" of epithelioma by radium (one personal case). Ulcerated forms are more accessible than non-ulcerated, but the latter can be cured without destroying the skin (young proliferating cells being more susceptible).

Darier[3] treated a case of recurrent epithelioma of the cheek, the side of the nose, and the upper eyelid by applications of radium—5 mg. of radium sulphate (activity 500,000) varnished on a copper plate 25 mm. square was applied for thirty minutes to each of the three lobes of the growth. These applications were repeated three days later and every eight days thereafter. The subsequent applications were over different scattered nodules, which represented invasion around the growth itself. The tumor fairly melted away (in ten days), and healed without any scar tissue and with the loss of only a small portion of the tarsal cartilage.

McKenzie Davidson reports 14 cures of rodent ulcer (epithelioma) by the application of the radiation from radium enclosed in a glass tube.[4]

Francis H. Williams and Samuel W. Ellsworth[5] use a capsule containing 50 mg. pure radium bromid covered with celluloid for skin cancer, etc. It is applied two to ten minutes twice a week, moving it about to secure uniform action.

E. Schiff[6] reports 2 cases of epithelioma of the face cured by radium. He believes that excision should be resorted to if prompt improvement does not follow radium or *x*-ray applications.

Radium Dosage in the Treatment of Epithelioma.—Epithelioma requires applications equal to a single one of about ten minutes with pure radium bromid, activity 1,800,000, weight 10 mg.

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[1] Bolletino della societa Lancisian degli Ospedali di Roma, No. ii, 1906.
[2] Berlin. klin. Woch., Feb. 15, 1906, p. 224.
[3] Le Radium, Sept. 15, 1906.
[4] Le Radium, Supplement to No. of June, 1906.
[5] Journal Amer. Med. Assoc., May 31, 1913.
[6] Münch. Med. Woch., Feb. 6, 1906.

A Case of Recurrent Endothelioma of the Vestibule of the Vagina (Fig. 782).—The disease had recurred very promptly after operation and in three weeks had regained its original size, about 1 inch in diameter. Secondary infection had required the removal of lymphatic glands in both groins and these also had recurred. The author's treatment consisted in the application of radium-coated celluloid with a radioactivity of 25,000 for from ten to twenty minutes, once in eight to fourteen days, to the vulvar tumor, and applications of the *x*-ray to the inguinal glands. There seemed for about two months to be an arrest of the progress of the disease. The vulvar tumor became flatter without any apparent change in breadth. Then there came a time when the tumor gradually increased in size and an irritating discharge began to flow from its surface. During the course of treatment, which extended over a period of about four months, there was no material extension of the inguinal enlargement, but the patient's general condition gradually became worse. She abandoned treatment then for the purpose of seeking the benefit of country air and a vacation from her duties as a school principal and died in a couple of months. The case was referred to the author by Dr. Hoag.

Fig. 782.—Endothelioma of the vulva. Treatment by radium and the *x*-ray did not effect a cure.

A Case of Disseminated Carcinoma of the Breasts and Axillæ Treated by Radium.—The man shown in Plate 16 was referred to the author by Dr. Beder. The right mammary gland and nipple had ulcerated away and there was another ulcer below that region. Both were adherent and covered with a red parchment-like epidermis, and were surrounded by an indurated margin projecting ½ inch above the level of the skin. Glandular masses larger than a hickory nut but smaller than a hen's egg were present in both axillæ and were widely scattered over the front of the chest. On the right side of the chest the skin over many of these was red, and they were evidently in a way to break down into ulcers.

Disseminated carcinoma of breast and axilla, showing improvement from radium treatment.

On the left side the nodules were smaller, white, and extended from the nipple in a cord-like mass up into the axilla. The disease had been of several years' duration; no operation even for removal of a microscopic specimen had been permitted. There was no history of syphilis, and two careful Wassermann examinations were negative. The clinical diagnosis had always been carcinoma, and if so, it was evidently similar to the cases of epithelioma cicatrizans, which are sometimes active for as long as eight years before causing death. My patient had lost weight and strength, the skin was adherent to the chest wall, and the use of the right arm was interfered with.

Treatment was by contact applications of 20 mg. of radium of 2,000,000 activity in a sealed glass tube $\frac{3}{10}$ mm. in thickness, enclosed in aluminum $\frac{1}{2}$ mm. thick and in thin, soft rubber. Treatments were three times a week for a month and after that once a week. At each treatment several individual nodules or parts of the nodular borders of the ulcers received an application equal to a total of fifteen minutes in each place. During the first month every growth on the right side had been treated in this way, and also the floor of the ulcers, but the left side had not been treated. At the end of this time all the nodular masses on the right side were perfectly flat, the cicatrized ulcers were no longer adherent, but could be raised and bent double. The arm could be raised to the greatest extent. The patient felt stronger and had gained 5 pounds in weight. The left side, untreated, showed marked improvement, strengthening the author's belief that the application of the *x*-ray and radium rays to cancer develops some antibody, which is carried through the system and in proper dosage produces benefit to cancer foci beyond the effective reach of the direct rays themselves.

Treatment was begun upon the left side, and the subsequent course of the case has been one of steady progress.

For a cancer of the jaw in a delicate old gentleman with heart disease, an entirely unfit subject for resection of the jaw, two applications of a tube of radium placed right in the broken-down cavity in the jaw-bone will effect a symptomatic cure. The glass tube, containing 20 mg. of 2,000,000 activity, should be enclosed in an aluminum treatment tube, and this may be applied for a total of from twenty to forty minutes, depending upon the destruction of tissue which is considered desirable, in addition to the specific effect of the gamma rays upon living cancerous tissues which are to be converted into living healthy tissues. If no destruction of tissue is desirable, a lead filter may be added and a soft rubber covering, and the length of time or the quantity of radium greatly increased.

Fungating epitheliomata are usually treated by Wickham[1] by direct contact, except for a thin rubber covering, with a flat disk varnish applicator, 1 inch in diameter, containing 10 mg. of pure radium salt with a certain amount of barium and other impurities; its radiation consists of 90 per cent. beta and 10 per cent. gamma rays. This is applied for an hour at a time every third day until about thirteen applications have been made. Stronger radium instruments, like glass tubes containing 20 or more milligrams of the pure radium salts, are effective with shorter applications, and, of course, weaker instruments require longer applications; but in any case the destruction of fungating epithelioma makes

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[1] Wickham and Degrais, Radiumtherapy, English Edition, published by Funk & Wagnalls, New York, 1910, an epoch-making work.

an unfiltered radiation desirable. The destruction is a molecular one, not accompanied by sloughing.

Epitheliomatous ulcer of the side of the nose which had not healed permanently by *x*-ray or cautery was treated by Wickham with an apparatus varnished with 10 mg. of pure radium salt, covered with $\frac{1}{100}$ mm. of aluminum and 1 cm. ($\frac{4}{10}$ inch) of cotton-wool as filters. Seven applications of one hour each, spread over a fortnight, were followed by gradual closing up and healing of the ulcer without any inflammatory reaction. The cure is apparently permanent.

Small ulcerating and crust-forming epithelioma has been treated by Wickham with 7½ mg. of pure radium salt without any metallic filter. Five applications of forty-five minutes each were made in the course of seventeen days. Decided reaction followed, with the development of a crust which, where it came away, left a perfectly sound surface apparently permanently cured.

Papillomata and senile warts are easily cured by a single strong application of unfiltered radium rays.

Carcinoma of the face with extensive swelling and ulceration was greatly improved by Wickham under applications of 60 mg. of pure radium salt through a lead filter 2 mm. thick for seventy-two hours over the center of the mass, and 15 mg. through the same thickness of lead over all other parts of the growth for fifty-two hours each.

Epithelioma of the parotid region was successfully treated by Wickham, using a cross-fire method by surface applications of four instruments containing 25, 25, 10, and 7½ mg. respectively, filtered by 1 or 2 mm. of lead, at different parts of the periphery all night for a fortnight and changing to other parts of the skin each night. Besides this an unfiltered application of 50 mg. was made over the ulcerated center of the growth for three hours altogether; and, in addition, a radium tube of 10 or 20 mg. of the pure salt screened by 1 or 2 mm. of lead and giving only highly penetrating rays, was inserted into the substance of the growth for four periods of twenty-four hours each. The growth broke down and sloughed out through the ulcerated place, and its base became movable, whereas it had formerly been adherent.

Cancer of the Breast.—Wickham's experience shows that it is better not to expose the lung to too much radium rays, but to use a cross-fire method. Even when the skin is red and looks like an abscess the effect of radium may be obtained without ulceration by a cross-fire method with 2 mm. or more of lead and long applications of strong specimens.

Wickham's use of radium in cancer of the breast is confined to the following cases:

1. "When the patient firmly refuses an operation.
2. "When the surgeon considers the case inoperable.
3. "*After* complete surgical removal if there are enough very powerful radium instruments to cover a large extent of the surface; otherwise, the *x*-ray is more effective. Sometimes in a young patient refusing mutilation by the loss of the breast, the surgeon may remove the whole subpectoral and axillary chain and the breast itself be treated by radium."

Applications of very powerful specimens of radium have been reported by Cameron of Pittsburgh. He saw very great temporary improvement in a case of cancer of the rectum from applications equal to 200 mg. of radium screened by 1 mm. of lead, and great reaction, followed by improvement after eight treatments of an hour each, in a case of cancer of the larynx.

He has observed the same toxic condition noted from x-ray applications upon a large cancerous mass, and it is sometimes even fatal. Caution must, therefore, be used regarding too long or too strong applications.

RADIUM PUNCTURE FOR CARCINOMA

Celluloid needles coated with radium of various radio-activities may be inserted into the substance of a tumor, and will cause sloughing of the tissues, so that the tumor may be extruded *en masse*. A radio-activity of 25,000 requires to be left in place for two to four days and the mass sloughs out a few days later. Stronger preparations may be used with a correspondingly shorter exposure. Cancer-cells are more susceptible than normal cells to the influence of radium, which, therefore, may be considered to exert a specific action. This, however, does not extend much more than ½ inch from the radium-coated surface, and it seems doubtful whether treatment by radium is any less likely to be followed by recurrence than surgical treatments. A large tumor, for instance, of the breast, would have to be punctured in a number of different places, and this would require a general anesthetic.

THERAPEUTIC USE OF NORMAL SALINE SOLUTION EXPOSED FOR TWO WEEKS TO THE RADIATION FROM RADIUM

A case in which the author employed this solution was that of a young woman who was seen in consultation with Dr. R. W. Hall. She was suffering from pyemia resulting from an abortion. There were abscesses about the hip and other large joints and a very high temperature. The treatment recommended consisted in cureting the uterus and administering an ounce of the radiated normal saline solution by hypodermic injection in the back. An immediate fall of temperature took place, and from that moment the patient began to improve, and though one or two more abscesses developed, they were not of a serious character and the patient was soon entirely well. The case is not regarded as demonstrating a therapeutic effect from the solution, but it may have been of benefit in connection with the surgical removal of the source of infection.

RADIUM IN EYE DISEASES

Cohn and others have found radium the best means of treating trachoma, conjunctivitis, and catarrhal folliculitis. A glass tube containing radium, or a small metal ball on the surface of which radium is varnished, may be rubbed over the affected mucous membrane for a few minutes.

E. Jacoby[1] has treated 8 cases of trachoma and 3 of follicular conjunctivitis with radium. Several series of four to eight applications of fifteen minutes each were made with 2 mg. of radium in a glass tube. He does not report as good results as those obtained from surgical treatment and chemic applications, but it is to be noted that his technic differs from that which is employed by the numerous other ophthalmologists, who report almost a specific action.

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[1] Deutsch. Med. Woch., Jan. 11, 1906.

RADIUM IN NERVOUS DISEASES

Rehns shows that exposure to radium tends to bring about a return of sensation in the anesthetic areas in locomotor ataxia.

Zimmern and Raymond call attention to the relief of the lightning pains in the same disease.

Abbe reports a case of exophthalmic goiter reduced in size by making a punctured wound in the thyroid gland and introducing a glass tube containing 0.10 gm. of a radio-activity of 300,000.

Darier has cured a case of supra-orbital anesthesia from a wound by two applications of radium. There is a beneficial effect upon paralytic and painful conditions of the nerves, and also upon certain nervous states which accompany convulsions or epileptiform attacks.

A **case of tic douloureux** which was treated unsuccessfully by applications of radium and of the *x*-ray, and which recurred after a resection of the inferior dental nerve, was treated by the author with encouraging results. The *x*-ray was applied to prevent the regeneration of the excised portion of nerve.

Capriati reports the cure of a case of facial neuralgia by applications of radium.

TONIC EFFECT UPON THE HEART

This has been observed by Tonta (Congress of Radiology, Milan, 1906).

Ionic Radium Treatment.—Radium is carried into the tissues by an electric current, regardless of the blood-current, quite deeply, and may remain fixed in the muscle or bone sufficiently to have a therapeutic effect.[1]

Radium ions passed through the tissues by electrolysis produced no effects appreciable six or eight weeks after the last ionization.[2]

Radio-active waters are carried into the tissues by the constant current.[3]

SUBSTITUTES FOR RADIUM

Uranium and thorium are not successful substitutes for radium even in larger quantities, to correspond with their weaker radio-activity.

Mesothorium is an extremely valuable substitute for radium. It was discovered by Hahn as a transformation product of thorium, and is (A. D. 1914) not at all in the state of purity attained by radium. The mesothorium now in use therapeutically consists of a large amount of inert matter, about 25 per cent. of radium, and less than 1 per cent. pure mesothorium. Not being able to isolate the latter, its properties remain somewhat uncertain, but it is calculated that pure mesothorium is 300 times as active as pure radium and that it loses 50 per cent. in five and a half years, while radium takes 1800 years to undergo an equal disintegration.

The mesothorium in use costs about two-thirds as much as a pure radium salt and requires a somewhat larger dose. Tested with an electroscope it shows an equal amount of gamma rays and can be distinguished from radium by the method on page 1134. In actual treat-

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[1] Haret, Danne, and Jaboin, C. R. Acad. des Sciences, clii, 800, March 20, 1911.

[2] H. Dominia, P. Haret, and A. Jaboin, C. R. de la Societe de Biologie, lxx, 431, March, 1911.

[3] Fabre, A. Zimmern, and G. Fabre, C. R. Acad. des Sciences, 798, March 20, 1911.

ment it is found to be more active superficially and somewhat less active through a great thickness of tissue.

Krönig and Gauss have made extensive use of it in the treatment of uterine cancer and fibroma. In both these conditions it has been applied inside the uterus combined with the *x*-ray directed through the abdominal wall, the perineum, and the back, to secure a cross-fire. Their success has been almost invariable in fibromyomata and has been good in cancer in an early and operable stage. At this stage the radiation treatment, preceding an operation to obliterate the lymphatic and blood-channels, offers the best chance for a permanent cure. The extensively disseminated inoperable cases are materially helped, but a permanent cure is seldom to be expected. One requires for this work from 20 to 80 mg. of mesothorium in a glass tube, with a filter of aluminum and lead or gold and an outer covering of rubber or cotton, to arrest secondary rays.

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