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MEDICAL ELECTRICITY

A

PRACTICAL HANDBOOK

FOR

STUDENTS AND PRACTITIONERS

BY

H. LEWIS JONES, M.A., M.D.

Fellow of the Royal College of Physicians, London; Medical Officer in Charge of the Electrical Department in St. Bartholomew's Hospital; late President of the British Electro-therapeutic Society; Honorary Fellow of the American Electrotherapeutic Association; Member of the Société Française d'Électrothérapie et de Radiologie; Editor of Medical Electrology and Radiology

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PREFACE TO THE FIFTH EDITION

In the present edition a rearrangement of the subject-matter has been adopted, and it is hoped that this change will make the book more convenient to students. Sections have been added on the current waves of medical coils; on the use of mechanical means for obtaining interrupted currents of measured duration; on the introduction of drugs by electrolysis; and on the treatment of rodent ulcer by zinc ions. A chapter has been added on the treatment of skin diseases by electricity, and the chapter on X-rays has been expanded to sixty pages. The author cordially thanks all those who have kindly lent blocks, for the illustrations form a very important part of a modern work on electro-therapeutics.

H. LEWIS JONES.

Harley Street,
September, 1906.

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MEDICAL ELECTRICITY

CHAPTER I

FIRST PRINCIPLES AND DEFINITIONS

Electroscopes—Conduction—Electromotive force—Capacity—Condensers—Leyden jar—Contact electromotive force—The voltaic cell—Electrolysis—Ions and electrons—Resistance—Ohm's law—Units of measurement—Primary and secondary cells—Magnetic field—Galvanometers—Electromagnetic induction—The induction coil—The dynamo-machine—Alternating currents—The transformer.

1. **Division of the Subject.**—The science of electricity may best be divided into four branches, as suggested in Sir Oliver J. Lodge's "Modern Views of Electricity," a book which should be read with care by everyone who wishes to have correct notions concerning the science. These four divisions are :

(*a*) *Static Electricity*, or electricity at rest.—This branch deals with the properties of electrically charged bodies, and with the phenomena of their charge or discharge.

(*b*) *Current Electricity*, or electricity in locomotion, which deals with the flow of electricity along conductors.

(*c*) *Magnetism*, or electricity in rotation.

(*d*) *Radiation*, or electricity in vibration.

Electricity in radiation is concerned in the phenomena of the X rays and of radio-active substances, and has come into the sphere of practical utility through the employment of electric radiations for the transmission of signals to a distance without wires. The discovery of electric radiation, and the first demonstrations of the transmission of electric waves to a distance without wires, were the work of Professor Hertz.

2. **Gilbert of Colchester.**—The foundation of the modern science of electricity may be considered to have been laid by a

medical man—Dr. Gilbert, of Colchester, Physician-in-Ordinary to Queen Elizabeth, and President of the Royal College of Physicians in the year 1600, the date of the publication of his treatise " De Magnete."

He extended to a large number of other substances the ancient observation that rubbed amber attracted light bodies. It seems, also, that we owe to him the word electricity, for he called all those substances electrics which, when rubbed, displayed the same attractive power for light bodies as amber (ἤλεκτρον, electrum) does, and soon afterwards the word electricity was introduced to indicate this power considered as a quantity capable of measurement.

All bodies, when rubbed with suitable precautions, are, to use Gilbert's term, *electrics*, or, rather, we should say that whenever any two bodies are rubbed together electrical separation occurs, one body becoming positively and the other negatively electrified, although in many cases it is difficult to observe this, owing to the escape of the charge. In fact, it is possible to arrange all substances in a list, such that when any pair of them is rubbed together the body higher in the list is positively electrified, while the other is negatively electrified to an equal extent.

Such a list is as follows : Cat's fur, polished glass, flannel, silk, shellac, ebonite. Thus, glass rubbed with cat's fur will be negatively electrified, while the same glass rubbed with silk will be positively electrified, and ebonite rubbed with cat's fur, flannel, or silk, is negatively electrified.

Positively electrified bodies repel each other, and negatively electrified bodies repel each other, but a positively electrified body and a negatively electrified body attract one another.

3. **Hypothesis of Fluids.**—Various hypotheses have been put forward to account for this action. Two of these may be noticed, as they supply a means for expressing electrical facts, though it must always be carefully remembered that in using these modes of expression we are making no assumptions as to the truth or the reverse of the hypothesis, but merely using a convenient analogy. The first is the " two-fluid " theory of Symmer, in which it is assumed that all matter contains an inexhaustible supply of a so-called electric fluid, which is capable of being split up, by friction or otherwise, into equal quantities of two fluids of opposite properties—viz., the so-called vitreous (positive)

and resinous (negative) electricities—and bodies that display the properties that we have said are signs of electrification are said to be charged with a certain quantity of one or other of these fluids, a certain quantity of positive or negative electricity. This hypothesis gives us, in many cases, a convenient method of expressing the facts, provided always that it be used as such, and is not pushed to the point of considering that the electric fluids are any real entities, or have any actual existence. It is obvious that it is an essential part of the hypothesis that both fluids shall always be produced in equal quantities.

In the "one-fluid" theory, which was favoured by Franklin, bodies that were positively electrified were looked upon as containing an excess of electric fluid, bodies that were negatively electrified were looked upon as suffering from a deficiency, while all bodies in the normal neutral state were looked upon as having neither an excess nor a deficiency.

4. **Conduction.**—If an electrified body, supported by silk strings or by a glass stem, be connected with another similarly supported non-electrified body by means of a wire for an instant, the second body will be electrified in the same sense as the first body, but to a less degree, the charge of the first body being conducted along the wire connection, and divided between the two bodies. If connection had been made with a glass rod, a stick of resin, or a silk thread, no transfer of charge would have occurred. The metal wire is, therefore, a *conductor* of electricity, the glass rod, etc., are not.

Substances vary very much in their power of conducting electricity. Thus, metals are good conductors, saline solutions and living bodies are fairly good ones; wood and cotton are poor conductors, while wool, silk, oils, resins, dry air at ordinary pressure, and most kinds of glass, conduct so slightly that they are used as insulators.

Gases at low barometric pressures conduct fairly well, and it will be seen hereafter that under certain special conditions a gas may conduct even at ordinary pressures.

The phenomena observed in the discharge of electricity through gases, and especially those seen in highly exhausted tubes, have led to the evolution of new theories of electrical conduction in general, and from them to new views of the nature of electricity and of the atomic constitution of matter. The time has not yet come for a detailed account of

the "electron" theory in a book like this one, but it will be again referred to after considering the nature of conduction in solutions, and also in discussing the behaviour of X-ray tubes and of radium and other radio-active bodies.

5. **Induction.**—A conductor can be electrified either by a transfer of electricity between it and another conductor, or by an alteration in the distribution of the electricity on its surface, without any transfer of electricity between it and another conductor. In the former case the body is said to be electrified *by conduction*, in the latter *by induction*.

Induction effects are produced whenever an electrified body is brought near any other body, and we may say, in the language of the two-fluid theory, that an electric charge in any body disturbs the equilibrium of the neutral fluid in the bodies near it, attracting an equal quantity of the fluid of opposite sign to their nearer sides, and setting free an equal quantity of the fluid of similar sign to itself at their remoter ends. On the removal of the inducing body, the induced charges recombine and disappear. If before the removal of the inducing body the conductor be touched with a finger, or otherwise be connected for a moment to earth, then that component of the induced charge, which is of like sign with the inducing charge, and is repelled, will escape by the channel so provided for it, and the subsequent withdrawal of the inducing body will therefore leave the conductor charged with a charge of the opposite sign.

6. **Electroscopes.**—The simplest means by which we may tell when a body is electrified is an instrument called an electro-

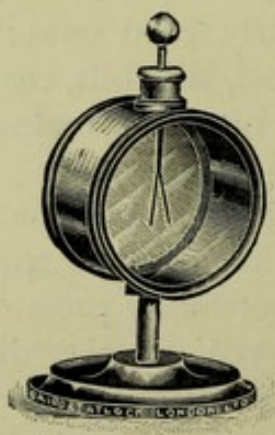

FIG. 1.—GOLD-LEAF ELECTROSCOPE.

scope. The usual form of electroscope is that known as the gold-leaf electroscope, which is made of two strips of gold-leaf

hung together from a wire. When these are electrified, they repel each other and diverge, and so indicate the presence of electrification. The instrument is usually enclosed in a glass jar, which serves as a support, and protects the gold-leaves from disturbances by currents of air (Fig. 1). This figure represents a simple form of electroscope, but many elaborated and improved forms have been devised.

With this instrument one can also discern the sign of the charge on an electrified body, for if a portion of the charge be transferred to the electroscope, and an additional charge be added from a positively electrified body—*e.g.*, from a glass rod that has been rubbed with silk—then, if the former charge was negative, the leaves will collapse, but if positive, they will diverge still further.

The best way of carrying out this test is as follows : Approach the charged body to the electroscope. It becomes charged by induction, and the leaves will diverge. Touch the plate of the electroscope with the finger for an instant, and they will collapse ; but on subsequently removing the body to be tested, they will again diverge under the effects of a charge of opposite sign to that of the body to be tested. Now bring up near the electroscope the rubbed glass rod. If the leaves collapse, the present charge is negative, and that of the original charged body was therefore positive.

7. **Electric Quantity.**—Hitherto electrification has been spoken of rather as a state or quality superinduced in bodies by certain processes. It is now necessary to arrive at a definite conception of this state as a measurable quantity—*i.e.*, as brought about by the presence of a real or hypothetical something which can be measured, and which is called electricity—a something which has been referred to, for convenience' sake, in the language of the " fluid " hypothesis as if it were an actual fluid, but which, it must be borne in mind, is not that, whatever else it may be. Let us suppose the existence of a something which is measurable, and which, when present in any body, endows it with the properties just described under the name of electrification, and which is called electricity.

This electricity, then, is of two kinds—one named positive, and one negative. It has been seen already that positive electricity repels positive, and that negative repels negative, while positive electricity attracts negative, and *vice versâ*.

This has to be expressed in terms of some unit, to be chosen once for all.

Maxwell ("Electricity and Magnetism") gives the following definition: "*Unit of Quantity.*—That quantity of electricity which, when supposed collected at a point, will repel an equal quantity of similar electricity collected at a point, and placed at unit distance from the first, with unit force, shall be taken as the unit quantity of electricity."

In this definition the unit quantity of electricity is made to depend on the units of length and of force, and this latter is defined with reference to the units of length, mass, and time. Hence the unit quantity of electricity can be completely defined in terms of the units of length, mass, and time. For scientific purposes these are taken as 1 centimetre, 1 gramme, and 1 second respectively.

In thus defining the unit quantity of electricity, the medium in which the action between the two charges takes place must be taken into consideration. It is assumed, however, that this is either dry air or, more precisely, a vacuum.

The attraction or repulsion between two quantities of electricity is proportional to each—*i.e.*, is proportional to the product of the two quantities. It is also inversely proportional to the square of the distance between them, always, of course, supposing that the two quantities are collected at two points.

8. **Electromotive Force, Potential.***—"Whatever produces, or tends to produce, a transfer of electrification, is called *electromotive force*. Thus, when two electrified conductors are connected by a wire, and when electrification is transferred along the wire from one to the other, the tendency to this transfer, which existed before the introduction of the wire, and which, when the wire is introduced, produces this transfer, is called the electromotive force from the one body to the other along the path marked out by the wire. If the potentials at different points of a conductor are different, there will be an electric current from the places of high to the places of low potential. The idea of electrical potential may be illustrated by comparing it with pressure in the theory of fluids and temperature in the theory of heat. If two vessels containing fluids are put into communication by means of a pipe, fluid will flow from the vessel in which the pressure is greater into that in

* Quoted from Maxwell's "Elementary Treatise on Electricity," p. 5.

which it is less till the pressure is equalized. Again, if two bodies at different temperatures are placed in thermal communication, either by actual contact or by radiation, heat will be transferred from the body at the higher temperature to the body at the lower temperature till the temperature of the two bodies becomes equalized. Similarly, when two electrified bodies are put into electric communication by means of a wire, electrification will be transferred from the body of higher potential to the body of lower potential.

9. **Electrometers.**—The only thing that can be observed in connection with electricity at rest is a difference of potential. It is possible to measure the quantity of electricity driven through certain instruments just in the way that a quantity of water driven through a water-meter can be measured, and some of these instruments will be discussed in a later paragraph ; but for the present we can only appreciate electrical charge by observing a difference of potential, and electroscopes and electrometers are instruments for showing or measuring differences of potential.

The gold-leaf electroscope has been shortly referred to above. The divergence of the leaves of this instrument may be taken as an indication that the knob or disc, or way by which electricity enters the instrument, is at a different potential to the walls of the room, or to that of the metal cage that surrounds some forms of the instrument, but obviously without further observation it does not tell whether the potential is higher or lower—*i.e.*, more positive or more negative—and further tests must be made to discover this. Neither does it give us more than the roughest indication of the amount of difference of potential. In cases where there is a great difference of potential, and a delicate gold-leaf electroscope is likely to be spoilt, rougher forms may be used—*e.g.*, leaves of thin aluminium or even pith balls suspended by linen threads may be used instead of the more delicate gold-leaf.

If it is required to measure a difference of potential an *electrometer* must be used. There are many forms of these, most of which are due to the inventive genius of Lord Kelvin. Descriptions of the various forms will be found in most textbooks, such as, for instance, in S. P. Thompson's " Lessons in Electricity and Magnetism," or the article " Electrometer " in the last edition of the " Encyclopædia Britannica."

10. **Distribution of Charge—Density.**—It has been observed

that the whole of an electric charge resides on the surface of a charged conductor, and this has been proved by direct experiment in many ways. It is found that while the distribution over a sphere is uniform, as might be expected from the symmetry of the figure, it is not so on conductors of other shapes. On these the charge per unit of surface, which is called the density, is greater the greater the curvature of the surface till at a sharp edge or a point the density becomes so great that at high potentials a discharge takes place. For this reason if a point is attached to a highly-charged conductor a stream of charged particles of air is repelled from the point, giving rise to a wind setting from the point and rapidly discharging the conductor. This action of points becomes of great importance in some electrical machines, and in some kinds of electrical treatment. In the first place, the presence of a point on a charged conductor renders it difficult to keep a charge on the conductor, however well it may be insulated. But the same effect will occur if a point be presented to a charged conductor ; for the charge, which we will suppose is positive, of the conductor acting inductively on the point will induce a negative charge at the point, the density of which will become so great that it will be discharged to the original conductor, neutralizing its positive charge, and leaving the conductor which bears the point positively charged if it is insulated. It is by this means that the prime conductors of most statical machines are charged from the excited plate or other movable part.

11. **Capacity.**—The quantity of electricity that is required to raise the potential of any conductor from zero to unity, all other conductors in the neighbourhood being kept at zero potential, is the measure of its *Capacity*.

As the charge resides only on the surface of a charged body, the capacity of a conductor is determined by the extent of its surface, and a body of a large surface has a larger capacity than a body of smaller surface.

When a conductor is said to have a given capacity it must not be thought that the conductor can hold only a certain fixed charge, in the way in which a glass bottle can be said to hold only so much water, because the quantity of electricity that can be put into a conductor of a certain capacity depends upon the potential or pressure at which it is charged. A body of unit capacity holds unit quantity when charged to unit potential, and holds ten times as much when charged to ten times the

potential. On this account it is necessary to know both the capacity of a conductor and the potential to which it has been charged before forming any idea of the quantity of electricity which it contains. The capacity of a conductor may be compared to the capacity of an elastic bag. The amount of air or of water that can be forced into an elastic bag depends upon the pressure at which it is forced in, and provided the bag does not burst it can be made to hold more and more by increasing the pressure at which it is charged.

The capacity of a conductor is increased by bringing near to it other conducting bodies, which are maintained at zero potential by being connected to earth, and it may be stated generally that the nearer the "earthed" conducting bodies are to a conductor the greater becomes the capacity of that conductor.

The importance of this point is well brought out by an example. The capacity of a sphere of 10 centimetres radius suspended freely in space is 10 units, but if another sphere of 11 centimetres radius be placed concentrically to it, so that the two spheres are separated one from another all round by 1 centimetre of air, and if the outer sphere be maintained at zero potential by connection to earth, then the capacity of the inner sphere is no longer 10 but 110 units, while if the radius of the outer sphere be reduced to $10\frac{1}{2}$ centimetres, the capacity of the inner one would become 210 units.*

12. **Condensers.**†—An apparatus consisting of two insulated conductors, each presenting a large surface to the other, with a small distance between them, is called a condenser, because when one conductor is connected to earth a small electromotive force is able to charge the other with a much larger quantity of electricity than if it stood alone—*i.e.*, its capacity is increased by the proximity of the other conductor.

The simplest form of condenser consists of two metallic discs supported on insulating stems, and facing each other, the intervening non-conductor or *dielectric* being air. If, now, a different dielectric, as, for example, a sheet of glass, be inserted instead of air, the capacity of the condenser will be found to be different,

* If a be the inner and b the outer sphere, then the capacity of a is given by the formula $\frac{ab}{b-a}$.

† Maxwell's "Elementary Treatise on Electricity," Chapter VIII.

and greater than before; thus the action across the dielectric depends on the nature of the dielectric.

Since a glass condenser has a higher capacity than an air condenser, glass is said to transmit induction better than air, or, in other words, glass has a higher *dielectric constant* or *specific inductive capacity* than air.

13. **Leyden Jar.**—The electrical condenser most often used in experiments on static electricity is that known as the Leyden jar (Fig. 2).

The ordinary form of this apparatus is a glass jar or bottle, coated inside and out with metal foil to within 2 or 3 inches of the top. Through the cork of the bottle a wire passes, terminating above in a knob and below in a chain, to make metallic contact with the inner coating. To charge the jar, the outer

FIG. 2.—LEYDEN JAR.

coating is connected to earth, and so kept at zero potential, while the inner coating is connected with the conductor of an electrical machine. The charge given to the inner coating acts inductively upon the outer coating across the dielectric of the jar, which is thus able to retain its charge. It may be discharged by bringing a metallic conductor, which is in connection with the outer coating, near to the knob of the jar. A spark will occur, and the jar is discharged.

The capacity of a Leyden jar depends upon the area of the surfaces coated with tinfoil, and also, from what has been said in § 11, upon the thinness of the glass of which it is made. If the glass be very thin it may give way under the strain when charged to a high potential, and be broken to pieces.

Condensers are also made for medical purposes by arranging

a number of sheets of glass and tinfoil alternately. The even numbers of the tinfoil sheets are connected together and form one armature of the condenser, the odd numbers forming the other.

Instead of the glass sheets shellac-varnished paper may be used as the insulator or "dielectric," and owing to its thinness a large capacity can easily be obtained in this way; but the tendency of the thin paper to be perforated if excessively high electromotive forces are applied to it should be borne in mind.

The discharge phenomena of a Leyden jar present many points of interest, and will be found to have important applications in some forms of medical apparatus. Generally the discharge takes place by a series of oscillations, which may be compared to the movements of a piece of watch-spring, or of an elastic rod which has been bent aside and allowed to fly back into its original position. The watch-spring, under these circumstances, swings to and fro several times before coming to rest.

In the case of the Leyden jar discharge, it will be found that the rate or "frequency" of its oscillations can be varied by varying the electrical dimensions of the Leyden jar or condenser, and those of the circuit through which the discharge takes place.

14. **Current Electricity.**—Volta observed at the end of the eighteenth century that when dissimilar metals, such as zinc and copper, were brought into contact in air electrical separation took place, and a small difference of potential (§ 8) could be observed between the metals, the zinc being positive to the copper, or at a higher potential. Under these circumstances this difference of potential does not efface itself by discharging across the junction of the two metals, as a difference of potential between two parts of a homogeneous conductor would do, because the electromotive force set up at the junction of the two metals could only discharge itself across the junction by a flow in the opposite direction to that in which it tends to cause a flow; but that is absurd. But if the two pieces of metal, while in contact, are immersed in some liquid that is capable of acting chemically on one of them—*e.g.*, dilute sulphuric acid—a "circuit" is formed, and the discharge can take place through the liquid, with the manifestation of changes therein, and a continuous discharge or current takes place round the circuit in the following way:—

Positive electricity passes across the junction from the copper to the zinc, and then from the zinc through the liquid to the copper again. If the connection of copper to zinc be by a wire,

as is usually the case, we may look on the junction as a sort of pump driving positive electricity round the circuit, so that it passes from the zinc across the liquid to the copper, and back to the zinc again, along the metallic connection between it and the copper, thus making a true circuit.

Such an arrangement is called a voltaic cell, and but for disturbances that will be more fully considered it would give a continuous current, till either the zinc or the exciting liquid (called the *electrolyte*) was exhausted.

15. **Theory of Arrhenius.**—The difference of potential in a cell, or its *electromotive force*, was formerly thought to be due to the contact electromotive force of the metals forming the poles of the cell, though in certain cases this might be slightly modified by the liquid used. This view has recently been examined again in the light of the fresh evidence which has been brought forward, in particular by the work of Van 't Hoff and Arrhenius. From their researches it seems probable that among the causes of the electromotive force of a cell the "contact E.M.F." of dissimilar metals occupies a minor place, while the phenomena occurring in the solution or electrolyte are of greater importance. The arguments in favour of this view may be found very clearly stated in McMillan's "Treatise on Electrometallurgy,"* from which the subjoined summary has been prepared, while those who wish to go more deeply into the matter should read "The Elements of Electrochemistry," by Max Le Blanc.†

Briefly stated, the steps in the line of reasoning are as follows:

(*a*) *Solution Pressure.*—The tendency of a body to go into solution when placed in a solvent may be called its solution pressure, and the different degrees of solubility presented by different salts, which are very varied, may be spoken of as differences in their solution pressures.

The solution pressure of any particular body is constant under any given set of conditions, but varies definitely with any definite change in these conditions.

(*b*) *Osmotic Pressure.*—When a soluble substance is placed in water it goes into solution, at first rapidly, but as the solution approaches saturation it dissolves more and more slowly. The dissolved molecules appear to exercise a pressure which opposes

* Griffin and Co., London, 1899.

† Macmillan and Co., London, 1896.

the solution pressure, and eventually a point of equilibrium is reached when the opposing pressure of the dissolved particles equals the solution pressure of the substance. This back pressure is known as osmotic pressure, and is susceptible of accurate measurement.

We may take as a concrete example the behaviour of zinc sulphate and distilled water. At 20° C. 53 parts of zinc sulphate will dissolve in 100 parts of water—that is to say, the solution pressure of the salt enables it to dissolve in the water to that extent. At 50° C. 66·9 parts will dissolve. At these temperatures the solution pressure of the zinc sulphate is balanced by the osmotic pressure of the solutions, when those proportions of the salt are present in solution in the water. If the warmer solution be cooled the equilibrium will be disturbed, the osmotic pressure will become stronger than the solution pressure, and solid zinc sulphate will be deposited from the solution. Conversely, if the cooled solution be warmed, its osmotic pressure will be reduced, and more of the salt will go into solution.

16. **Ionization.**—The whole class of compounds known as electrolytes break up, or are *dissociated*, when dissolved in water. Sodium chloride, for example, breaks up more or less completely into the two separate parts, Na (sodium) and Cl (chlorine). Hydrochloric acid dissociates into H and Cl, zinc sulphate into Zn and SO_4, and so on, each molecule forming two separate entities, which are known as ions. The ions carry definite charges of electricity, those of the metals carry positive charges, those of the non-metals (chlorine, acid radicals, and the like) carry negative charges. The ions, SO_4, Cl, H, Na, etc., do not manifest the chemical properties of their elements as ordinarily recognised. The difference is one of their electrical charges, and when the ions are deprived of their charges the element reappears in its ordinary form. In the solution the ions are equally diffused, and the positive electricity of the one set exactly neutralizes the negative electricity of the other set, so that the dissociation of a salt does not affect the apparent electrical condition of the solution.

17. **Electrolytic Solution Pressure.**—If these conceptions be applied to the case of metals immersed in solutions, it is found that they possess the property of passing into solution and of forming ions. This special tendency of metals to dissolve with the formation of ions is called their electrolytic solution pressure,

to distinguish it from the simpler solution pressure of salts. Just as osmotic pressure opposes solution pressure, so it opposes electrolytic solution pressure. In the case of a metal immersed in solutions of its own salts the osmotic pressure of the ions of the metal already in solution tends, in proportion to their number, to prevent the passage of fresh ions of the same kind into solution.

The electrolytic solution pressures of different metals—that is to say, the tendency of different metals to become ionized when in contact with a liquid—varies very greatly for the different metals.

The formation of ions from a metal requires definite positive electrical charges, and if ions are formed when a metal is immersed in a liquid they must exist in the solution without any balance of negatively-charged ions, such as are formed when a salt like NaCl or $ZnSO_4$ is dissolved. Consequently the liquid must acquire a positive charge, and as both kinds of electricity must be simultaneously developed whenever electrical energy comes into existence, the metal acquires an equal negative charge. Electrical equilibrium is thus maintained, but the tendency of the metal to continue forming positive ions is opposed.

It has been observed, experimentally, that certain metals become negatively charged when immersed in an electrolyte, while others acquire a positive charge. Those of the former class have an electrolytic solution pressure which is large, and have a strong tendency to form ions, and those of the latter class have an electrolytic solution pressure which is low, and with them ionization does not take place, except with special electrolytes. Tables have been drawn up of metals arranged in order according to their behaviour in this respect, and from the point of view of their action when used as the metals of a voltaic cell they may be divided into those whose electrolytic solution pressure is greater than that of hydrogen, and those others whose electrolytic solution pressure is less.

An abbreviation of such a table would be :

Zinc.
Iron.
Lead.
Hydrogen.
Copper.
Silver.

Those metals whose electrolytic solution pressure is greater than that of hydrogen are able to deprive hydrogen ions of their positive charges, and thus to displace hydrogen in an electrolytic cell. They are the metals which dissolve in acids with evolution of hydrogen gas.

18. **Voltaic Cell.**—If the voltaic cell be now considered as an electrolyte, H_2SO_4, in which the two dissimilar metals, zinc and copper, are immersed, it will be seen that each will exert its own solution pressure, and will become negatively or positively charged. The zinc, by virtue of its high electrolytic solution pressure, tends to form positively-charged zinc ions, and in doing so becomes negatively electrified. The copper has almost no tendency to become ionized, and acquires a positive charge.

On joining the two metals by a wire, an electrical system or

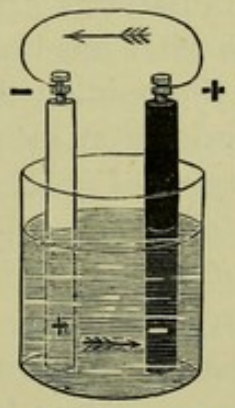

FIG. 3.—VOLTAIC CELL, SHOWING DIRECTION OF FLOW INSIDE AND OUTSIDE.

circuit is formed. The copper communicates its positive charge through the wire to the zinc, and the zinc is thereby enabled to supply positive charges to its ions, which accordingly go into solution; the hydrogen of the electrolyte gives up its positive charges to the copper, and appears at the surface of the copper in the form of bubbles; the SO_4 ions remain unaffected. So long as zinc ions continue to go into solution, and hydrogen ions continue to give up their charges of positive electricity to the copper, the "current" of electricity flowing in the wire from copper to zinc will continue; but as the liquid becomes richer in zinc ions, their osmotic pressure will begin to oppose the electrolytic solution pressure of the zinc. Also, as the free available hydrogen ions diminish, through being expended, the renewal of the positive charge of the copper will begin to fail, and the action of the cell will fall off.

It is customary in some textbooks to speak of the zinc plate of a battery as the positive plate, and the copper or other plate as negative, while the terminal attached to the zinc plate is called the negative pole, and that attached to the copper the positive. The origin of this very confusing nomenclature is, no doubt, the fact that in the liquid the positive direction of flow of the current is from zinc to copper, and that zinc is said to be electropositive to copper. But in the connecting wire the positive direction of the flow of current is from copper to zinc (see Fig. 3), and as this is the portion of the circuit that we are most concerned with, the word positive will be used to denote the positive pole of the battery, and also the plate connected with it, when it is necessary to specify this. This is in conformity with the usage of electrical engineers, who speak of the peroxide plates in an accumulator as " positives."

19. **Electrolysis.**—From what has been learnt in the preceding paragraphs we can form the opinion that the solution of a salt in water leads to its dissociation into ions. This dissociation is incomplete except at stages of great dilution, but nevertheless we can regard such a solution as containing free ions more or less abundantly. A solution containing free ions is called an electrolyte, and acts as a conductor; indeed, the conductivity depends upon the presence of free ions, and a liquid conducts electricity well or badly in proportion to the degree to which it is dissociated, or (which is the same thing) to the number of free ions which exist in it. Water, for instance, conducts very badly when pure, and it has been calculated that its dissociation is very slight indeed.

The ions in an electrolyte through which no current of electricity is passing have no definite arrangement in the liquid so far as we know. Whatever motion there may be among them has no uniformity of direction, or at least has no tendency to any separation or sorting out of the positively and negatively charged ions.

If an electric current be produced in an electrolyte, as can be done by dipping into it two electrodes which are connected respectively to the positive and negative poles of a source of electricity, an orderly motion of the ions is brought about, and decomposition of the electrolyte takes place. The negatively-charged ions will move towards the positive pole, and on reaching it they will give up their charges to the pole and lose their

existence as ions, and the positively-charged ions will do the same at the negative pole. Thus with hydrochloric acid as the electrolyte, gaseous hydrogen and chlorine separate in unelectric form at the electrodes,* the hydrogen at the negative electrode or kathode, and the chlorine at the positive electrode or anode.

The course of events is, however, not always so simple as in the instance just given. Even in that case it would be necessary to employ as the anode of the cell a substance whose electrolytic solution pressure was extremely small. Otherwise no chlorine would be liberated in the gaseous form, for the positive charges supplied to the anode from the external circuit would be expended, not in neutralizing the negative charges of the chlorine ions, but in supplying positive charges to ions of the metal of the anode, which would accordingly enter the solution in the ionic condition, and would exist there side by side with the chlorine ions, whose negative charges would thus be balanced by the positive charges of the newly-formed metallic ions. In the case of an electrolyte of sulphate of copper with metallic copper electrodes the passage of the current causes the copper ions in the electrolyte to move towards the kathode, and there to give up their charges and to appear as metallic copper, while at the anode copper ions are formed at the expense of the copper electrode, and pass into the electrolyte ; the effect, therefore, is the transport of copper from the anode to the kathode, and the latter gains while the former loses weight. The SO_4 ions associated with the copper in the electrolyte migrate towards the positive pole, and as the action continues they tend to become concentrated in that part of the solution.

If the electrolyte be a solution of a salt of an alkali metal, as, for example, sodium sulphate, and the electrodes be of platinum, the effects produced by the passage of a current again seem different, and this is on account of certain " secondary reactions." Suppose such a solution, to which some litmus has been added, be electrolyzed, on the passage of the current gases will be evolved at both poles, and the litmus will show the presence of acidity at the anode and alkalinity at the kathode. The gas evolved at the kathode is hydrogen, that at the anode oxygen, and the explanation given is as follows :

* Le Blanc, " Electrochemistry," Chapter IV., " The Migration of the Ions."

The electrolyte contains free sodium ions and free SO_4 ions, also a few H and OH ions from the dissociation of the water, which occurs only to a very slight extent. During the passage of the current the sodium ions migrate towards the kathode, part with their charges, and deposit sodium in the metallic form. Sodium, however, is decomposed by contact with water into sodium hydrate and hydrogen; accordingly hydrogen gas is evolved, and the liquid near the kathode becomes alkaline from the dissolved sodium hydrate. At the anode the SO_4 ions also lose their charges, and the SO_4 undergoes a secondary reaction with the molecules of water present to form H_2SO_4 (sulphuric acid) and oxygen, which is evolved. Objections have been raised to this explanation of the events, but it seems very likely that sodium is really set free in the form of metal at the kathode, because if mercury be used as the kathode the evolution of hydrogen is decreased, and metallic sodium can be extracted from the mercury by suitable treatment.

The laws of electrolysis enunciated by Faraday are as follows:

(*a*) *The amount of chemical action is equal at all parts of a circuit.* *E.g.*, if several electrolytic cells, as they are often called, be arranged in a circuit, the amount of decomposition will be the same in each. If some of the electrolytic cells contain an acid and others contain sulphate of copper solution, the quantities of hydrogen or copper liberated will be proportional to their chemical equivalents.

(*b*) *The amount of any ion liberated in any given time is proportional to the strength of the current, and to the chemical equivalent of the ion.*

The chemical equivalent for hydrogen is unity, therefore the weight of hydrogen liberated by 1 ampère running for one second—*i.e.*, by 1 coulomb of electricity—is the electrochemical equivalent of hydrogen. For any other ion the product of the weight liberated by 1 coulomb, multiplied by the chemical equivalent of the ion, is called the electrochemical equivalent of that ion. The electrochemical equivalent of silver is very nearly 0·001118 gramme per coulomb, and the quantity of silver which 1 ampère would deposit in an hour is 4·0246 grammes.

20. **Ions and Electrons.**—We have seen in the preceding paragraphs that the atom with its charge is called an ion. Lodge,*

* "On Electrons," by Sir Oliver Lodge, *Journal of the Institution of Electrical Engineers*, 1902.

in discussing conduction in liquids, says that we "learn from electrolytic conduction that every atom carries a certain definite charge or electric unit, monads carrying one, diads two, triads three, but never a fraction; that in liquids these charges are definitely associated with the atoms, and can only be torn away from them at the electrodes; that the current consists of a procession of such charges travelling with the atoms, the atoms carrying the charges, or the charges dragging the atoms, according to from which point of view we please to regard the process." And subsequently, in speaking of electric discharges in gases at very low pressures, he says: "The behaviour of charged particles seems to indicate that they must in some cases be something smaller than atoms. It seemed hardly likely that material atoms could behave in the way they did, so it was recollected that it had occurred to some philosophers, among them Dr. Johnstone Stoney, that electric charges really existed on an atom in concentrated form, acting as satellites to it, so on that view it was just possible that these flying particles (in the vacuum tube, etc.) might not be atoms at all, but charges without the atoms, the concentrated charges detached, knocked off, as it were, in the violence of the discharge, and afterwards going about free."

It is to this conception of the charge alone, considered without its atom, that Dr. Johnstone Stoney has given the name of "electron."

It has been shown conclusively that ultra-atomic corpuscles negatively charged exist in the current through a highly exhausted tube, and their mass has been computed to be about the $\frac{1}{1000}$ of that of a hydrogen atom, and Professor J. A. Fleming writes:—"Thus we reach the idea of something much smaller than an atom, and usually existing attached to an atom of matter, but capable of being detached from it, and of existing in a free condition as a negative electron, or unit of negative electricity. Hitherto no positively-charged corpuscle or positive electron has been observed, so the situation is this, that positive charges are only known in association with masses as large as atoms, while negative charges are known in association with the very much smaller corpuscles or electrons. The question has then become debated as to whether we can distinguish between the corpuscle and the electric charge it carries, and, if so, in what way. In other words, can we have an unelectrified corpuscle or atomic

fragment, or is the corpuscle so identified with its electric charge that they are one and the same thing? At the present moment we have no evidence that we can separate the electron charge from the corpuscle itself. If this is the case, then the corpuscles, taken together, constitute for all practical purposes negative electricity. For this reason it is sometimes usual to speak of the corpuscle carrying its charge of 1 electron of negative electricity simply as an electron, and to drop all distinction between the electric charge and the vehicle in or on which it may be conveyed." Lodge has taken the view that there is no vehicle or unelectrified part of a corpuscle, and has expressed himself as follows:—"Our present view of an atom of matter, therefore, is something like the following: Picture to one's self an individualized mass of positive electricity diffused uniformly over a space as big as an atom, say a sphere of which two hundred million could lie edge to edge in an inch, or such that a million million million million could be crowded tightly together into an apothecary's grain. Then imagine disseminated throughout this small spherical region a number of minute specks of negative electricity all exactly alike, and all flying about vigorously, each of them repelling every other, but all attracted and kept in their orbits by the mass of positive electricity in which they are embedded and flying about."

"In so far as an atom is impenetrable to other atoms, its parts act on the sentinel principle, not on the crowd principle. There are two ways of keeping hostile people out of an open building: one is to fill it with your own supporters, another is to place an armed policeman at every door. The electrons are extremely energetic and forcible, though in bulk mere specks or centres of force. Every speck is exactly like every other, and each is of the size and weight appropriate to the electron. Different atoms—that is, atoms of different kinds of matter—are all believed to be composed in the same sort of way; but if the atoms of a substance are such that each possesses twenty-three times as many electrons as hydrogen has, we call it sodium; if each atom has 200 times as many as hydrogen, we call it lead or quicksilver; if it has still more than that, it begins to be conspicuously radio-active."

"Matter, then, appears to be composed of positive and negative electricity and nothing else. All its newly-discovered as well as all its long-known properties can thus be explained."

21. **Ionization of Gases.**—It was mentioned in § 4 that under certain special conditions a gas may conduct at ordinary pressures, and in recent years the phenomenon of electric conduction in air at the ordinary atmospheric pressure has become familiar to medical men in connection with X-ray work and radio-active bodies, and also in connection with ultra-violet light. It is therefore important to consider this question with the object of obtaining clear ideas as to what is meant by the ionization of air or of other gases.

Manifestly the conditions are not strictly comparable to those occurring in an electrolyte, as, for example, in a solution of sodium chloride, for whereas the solution contains an abundance of negatively and of positively charged ions produced by the dissociation of the salt, a simple gas such as oxygen or nitrogen cannot become dissociated in the same manner. The ionization of a gas can be understood in the light of the theory of electrons, for it can then be explained as the breaking up of the atoms of the gas into negatively-charged electrons and positively-charged remainders, and this is doubtless the explanation of what happens when a gas is rendered conducting by any one of the well-known methods, such as exposure to Roentgen rays, to radium rays, to ultra-violet light, or to heat, as, for instance, in a flame.

22. **Heating Effects of a Current.**—A voltaic cell may be regarded as an apparatus by means of which the energy of the chemical action between the zinc and the electrolyte, the ionization of the zinc, can be in part converted into electrical energy, and the process may be regarded as a combustion in which the fuel is the zinc. If a piece of common zinc be simply dissolved in sulphuric acid in a test-tube the energy liberated serves only to warm the contents of the tube, but when the zinc is arranged in a voltaic cell some of the energy can be utilized in the form of an electrical current flowing through the circuit, and this current can be made to do work, or can be again converted into heat in any part of the external circuit of the cell. When an electrical current flows through a circuit energy is absorbed by the resistance of the circuit, and is dissipated in the form of heat, or, in other words, a wire carrying a current becomes heated by the passage of the current through it. The amount of heat generated depends (1) upon the resistance of the wire, being proportional to the resistance, and (2) upon the magnitude of the current, being

proportional to the square of the current. Accordingly, when it is wished to avoid the production of heat and the consequent loss of energy in a circuit, the conductors should be of low resistance ; and conversely, when the current is to be used for the production of heat, as in the wire loop of a galvano-cautery instrument, or in the filament of an incandescent lamp, then the resistance of the part of the circuit which is to be heated must be made as high as may be necessary for the circumstances of the case, and a relatively bad conductor must be chosen for that portion.

23. **Resistance.**—A current is set up in a conductor by electromotive force—that is to say, there will be a current in a conductor if there be a difference of potential between its ends. It is soon found in working with currents that with different conductors different currents are produced by the same electromotive force. There is, therefore, another factor that determines the magnitude of the current besides the electromotive force, and this factor is called the *resistance* of the circuit.

The resistance of a conductor is the inverse of its conductivity, and the conducting qualities of a body may quite well be expressed in terms of its resistance ; thus the same idea is conveyed by saying that copper has a high conductivity, or that it has a low resistance. It is customary and convenient to speak of the resistances of bodies rather than of their conductivities.

The resistance of a conductor depends upon the material of which it is made, and upon its length and its thickness. Thus a thick wire has a lower resistance than a thin wire of the same length and material, and a short wire has a lower resistance than a long wire of the same thickness and material. This is expressed by saying that the resistance of a conductor is directly proportional to its length, and inversely so to its cross-section.

The electrical resistance of any material is a property peculiar to that material, just as its hardness or colour or density is. Most metals are good conductors, but they vary greatly among themselves in their electrical conductivity. Silver is the best conductor of electricity, and copper comes near to it. Platinum has about six times the resistance of silver, and iron has a resistance slightly greater than that of platinum. As a general rule

alloys have a higher resistance than the pure metals, German silver having about fourteen times the resistance of copper. Tables showing the relative conductivity of metals and other bodies are given in textbooks such as S. P. Thompson's "Lessons."

Tables of resistance are also made with the *specific resistances* of the materials tabulated. The specific resistance of a material is defined as the resistance of 1 cubic centimetre of the substance considered.

If the specific resistance of a substance is known, the resistance of any wire or rod of that substance can be calculated.

In general the resistance of metals increases with temperature. Some alloys have been made in which variations of temperature have very little effect upon the resistance, and these are of special value for the construction of standard resistances. That of carbon, however, decreases considerably. The carbon filament of an incandescent lamp has nearly twice the resistance cold that it possesses when hot.

Just in the same way as the resistance of a metal or other solid conductor is considered, so we may consider the resistance of a liquid or electrolyte.

The fact that electrolysis is taking place in an electrolyte does not prevent the consideration of its resistance in the same way as that of a non-electrolyte. Compared with metals the resistances of solutions are high; thus a salt solution may have a specific resistance upwards of a million times greater than that of copper.

As heat generally increases the resistance of metallic conductors, and decreases that of electrolytes, it is necessary to take account of temperature whenever measurements of resistance are to be made.

The measurement of resistance in electrolytes may be complicated by electrochemical relations existing between the electrolyte and the poles of the electrolytic cell, and electromotive forces set up in the cell itself may obscure or vitiate the results if they are not properly recognised and guarded against.

24. **Ohm's Law.**—The law showing the relation between electromotive force, resistance, and current was enunciated by Dr. G. S. Ohm, and is known as Ohm's law. It is as follows: *The strength of the current in any circuit or part of a circuit varies*

directly as the electromotive force in that circuit, and inversely as the resistance of the circuit. This may be expressed in symbols thus :

$$C = \frac{E}{R},$$

where C stands for the current, E for the electromotive force, and R for the resistance. From this formula we obtain in addition $E = CR$, or $R = \frac{E}{C}$. Thus we can calculate either C, E, or R if the values of the other two symbols are known or can be measured.

25. **Practical Units.**—The electromagnetic units, as in the case of the electrostatic units, are all ultimately defined in terms of the units of mass, length, and time, and as in all electrical and other scientific calculations these are taken to be 1 gramme, 1 centimetre, and 1 second respectively, the system of units is known as the absolute or centimetre-gramme-second (C.G.S.) system. It is found, however, that for practical calculation and use these units are not of a convenient size—*e.g.*, the units of electromotive force and of resistance are inconveniently small, and that of current is inconveniently large. The following system of units derived from these has therefore been adopted for practical use.

Electromotive Force.—The practical unit is called the *Volt.* It is a little less than the electromotive force of one Daniell's cell (see § 31).

Resistance.—The practical unit of resistance is called an *Ohm.* The Paris Congress of Electricians in 1884 defined a unit of resistance to be called a *legal Ohm.* It is represented by the resistance of a column of pure mercury at 0° C., of a uniform cross-section of 1 square millimetre, 106 centimetres long, and weighing 14·4521 grammes; it is slightly less than the true ohm. of 10^9 C.G.S. units.

Current.—The current which is given by an electromotive force of 1 volt acting through a resistance of 1 ohm is called 1 *ampère.*

Quantity.—One ampère flowing for one second carries 1 *coulomb* of electricity past any point in the circuit. Another unit of quantity much used by engineers is the quantity of electricity which would be carried by 1 ampère in an hour. This is called an *ampère-hour.* It is equal to 3,600 coulombs.

Capacity (see § 11).—That capacity which would require 1 coulomb to charge it to 1 volt is called 1 *Farad*.

These names commemorate the labours of Volta, G. S. Ohm, Ampère, Coulomb, and Michael Faraday.

Even these units are inconveniently great or small at times, so certain prefixes are used to the names to denote multiples or submultiples of these quantities. Thus, a *megohm* is one million ohms, a *microvolt* is one-millionth of a volt, a *microfarad* is one-millionth of a farad, a *milliampère* is one-thousandth of an ampère ; this last is the unit of current used in medicine.

The energy expended in a conductor may be calculated from the current in the conductor and the electromotive force acting upon it, the figure obtained by multiplying the electromotive force (in volts) by the current (in ampères) giving the rate of the expenditure of energy in terms of a unit known as a *watt*.

If E represents the electromotive force and C the current, then the watts, W, expended in the conductor are expressed by EC.

In any simple conductor the energy expended takes the form of heat. We are consequently able to calculate the rate at which heat is generated in the conductor, and if we know its specific heat, and the rate at which it loses heat at its surface, we can calculate the temperature after the current has passed for any given time.

A watt is not a measure of work done, but of the rate of doing work. To obtain a measure of work done the time during which it goes on must be also considered. Thus one watt for one hour, or, shortly, one *watt-hour*, is a measure of work done.

By Ohm's law $E = RC$, and if in the equation $W = EC$, RC be substituted for E, we obtain the formula $W = C^2R$, for the rate of doing work, for losses in a conductor, or for the heating effects of a current traversing a conductor.

The Board of Trade unit in which the energy sold to consumers by the electric light companies is measured is 1,000 watt-hours, and costs about sixpence.

This amount of energy can be made up in various ways ; for example, taking the ordinary pressure of supply as 100 volts, ten ampères at that pressure for one hour, or one ampère for ten hours, alike represent the amount of energy of one unit. An ordinary incandescent lamp of sixteen candle-power requires about sixty watts to keep it at a proper degree of brightness, and

on a circuit of 100 volts it takes a current of 0·6 of an ampère. Five of these lamps would use 300 watts, and if kept going for five hours the amount of energy absorbed would be 1,500 watt-hours, or one Board of Trade unit and a half, costing ninepence, if the price of the unit were sixpence.

26. **Thermo-electricity.**—In 1822 Seebeck discovered that a difference of potential could be produced by heating or cooling the point of junction of two dissimilar metals. If a rod of bismuth be soldered to one of antimony, and the free ends be connected by a wire, a current will flow through the circuit so formed if the junction of the bismuth and antimony be heated or cooled, and the current will continue to flow so long as the junction is maintained at a different temperature to the rest of the circuit. When the junction is heated the direction of flow is from bismuth to antimony through the heated part, but when it is cooled the current flows in the opposite direction. Other metals, and some alloys and minerals, show the same effects. The electromotive forces set up are small, but by the combination of many couples thermo-electric batteries or thermopiles have been constructed for practical use. The opposite effect can also be observed. It was discovered by Peltier, and is usually known as the " Peltier Effect." It is that if a current be driven through a thermo-electric junction the junction is cooled or heated according to the direction of the current. Thus a current passed from bismuth to antimony cools the junction, and a current from antimony to bismuth heats it.

27. **Chemical Batteries.**—Numerous modifications of Volta's original cell have been proposed from time to time with the object of improving it, so as to obtain as high an electromotive force as possible, to diminish the internal resistance, and to secure constancy of action. For medical work the most important point of all is to find a cell which will remain for a long time in good order without attention, and in which no wasteful chemical action goes on when the battery is not in use. On this account the Leclanché cell (§ 34) or some modification of it has almost entirely displaced the other types for medical purposes.

The limit of electromotive force that can be obtained from a single cell is soon reached, since, as shown in § 17, it depends almost entirely on the electrolytic solution pressure of a metal or substance. Tables are found in electrical textbooks of metals and other conducting bodies arranged in order, the most " electro-

positive " at the head of the table, the most " electronegative " at the foot. An abbreviation of such a table is the following :

Electropositive.
Sodium.
Magnesium.
Zinc.
Iron.
Lead.
Copper.
Silver.
Mercury.
Platinum.
Carbon.
Lead peroxide.
Electronegative.

The similarity between this table and that given in § 17 is easily seen.

This order is given for the elements in the presence of dilute acid ; under other circumstances the order is liable to some alteration by reason of the influence which may be exerted by osmotic pressure and electrolytic solution pressure under varying conditions.

It follows that the cell with the greatest electromotive force would be one the poles of which consisted of the two materials at the extreme ends of the table, and many of the improvements in batteries made with the object of increasing the electromotive force have been by substituting bodies further down the list for the copper plate of Volta's cell. Thus in Smee's cell we find a platinized silver plate, and in Groves' cell a platinum plate, while in Bunsen's carbon is used. The best of these cells when working properly have an electromotive force of something under 2 volts ; that of a Bunsen's cell is from 1·8 to 1·9 volts.

As will be seen in the description of secondary batteries, a positive plate of peroxide of lead affords a means of getting a high electromotive force, and the combination of it with a zinc negative plate has been suggested under the name of the zinc-lithanode battery, and has an electromotive force of 2·5 volts per cell.

If several cells be coupled together in series, that is to say, with the negative pole of the first joined to the positive pole of

the second, and so on, the electromotive force of the combination measured from the positive pole of the first to the negative of the last cell will be equal to the sum of the electromotive forces of the cells taken separately; thus, when high electromotive forces are required, the arrangement of a sufficient number of cells in series provides a means of obtaining it. If ten cells of an electromotive force of 1·5 volts apiece be arranged in series, the electromotive force of the whole battery will be 15 volts. In medical treatment an electromotive force of 30 or 40 volts may be required, and a medical battery is, therefore, provided with a suitable number of cells connected together in series to give such a voltage.

28. **Internal Resistance of Cells.**—This is determined by the nature of the fluid in the cell, by the distance between the plates, and by the area of the plates. The internal resistance is low if the plates be large and close together, and high if the plates be far apart or small. If the whole circuit of a cell be considered, and divided into two parts, the external circuit in the wire, and the internal inside the cell itself, then a comparison of the resistances of the two parts will show what proportion of the total electrical energy of the battery is available for use in the external circuit, and what proportion is expended uselessly inside the cell itself; for example, in the case of a cell having an internal resistance of 3 ohms, and connected through an external resistance of 6 ohms, the energy expended in the outside circuit will be two-thirds, and that expended inside the cell will be one-third of the total. If the electromotive force of the cell be 1·5 volts, then one-third of the total fall or slope of potential (or 0·5 volt) will be used up in the cell, and the remaining two-thirds (or 1 volt) will represent the working electromotive force of the cell available for the outside circuit.

If the external resistance be 997 ohms, and the electromotive force and internal resistance be as before, then the electromotive force acting upon the external circuit will be very nearly the same as the full voltage of the cell; actually it will be in the ratio of 997 to 1,000, or 1·495 volts.

Thus one sees that in certain cases the internal resistance of a cell is an important factor in determining its value as a source of current, while in other cases it is insignificant. In working with the large resistances of the human body, the internal resistance of the cells composing the battery is an unimportant matter,

as it forms only a small fraction of the total resistance of the circuit, and the waste or loss of electromotive force inside the cells is, therefore, a small fraction also.

In working with low external resistances, as for the heating of a galvano-cautery instrument, and to a less degree in the illumination of parts of the body by incandescent lamps, the internal resistance of the cells becomes important, and special forms of cell with low internal resistances are required for such work. Cells which have a low internal resistance are much more quickly run down if allowed to go on discharging through a circuit of low resistance than are those with a high internal resistance. Accumulators, with their very low resistances, need special care in this respect, for if treated in that way ("short circuited") they may discharge at a relatively enormous rate, and be not only run down, but also permanently injured thereby.

29. **Arrangement of Cells.**—The arrangement of cells in series has already been alluded to, and is represented in Fig. 4. Cells

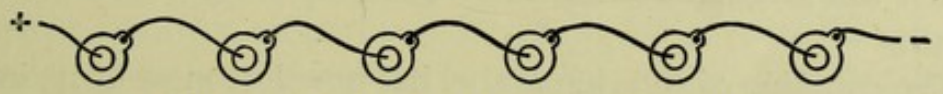

FIG. 4.—SIX CELLS ARRANGED IN SERIES.

may also be arranged in parallel (Fig. 5)—that is to say, two or more cells may have their positive poles connected together to

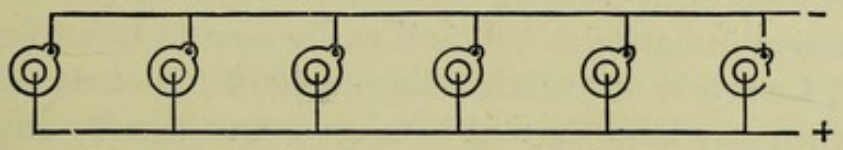

FIG. 5.—SIX CELLS ARRANGED IN PARALLEL.

form one pole of the battery, and their negative poles in like manner to form the negative pole. When cells are connected in series the electromotive force of the battery is the sum of the electromotive forces of the cells composing it; the internal resistance of the battery is also the sum of the internal resistances of the cells. When similar cells are connected in parallel, the electromotive force of the combination is no more than the electromotive force of one of its components; but its internal resistance is diminished in proportion to the number of cells coupled together. With six cells in parallel the internal resistance is one-sixth of that of one cell. It is sometimes useful to couple

up the cells which are at hand in the best manner for obtaining the desired result, as the following example will show :

Suppose the resistance of a cautery is 0·1 ohm, and the cells to hand are of 1·6 volts each and 0·5 ohm internal resistance, and suppose that the cautery requires 8 ampères to heat it. If ten cells are coupled up in series we shall indeed get an electromotive force of 16 volts acting through a resistance of 5·1 ohms, and this will give a current of a little over 3·1 ampères, but if they are coupled in parallel the battery resistance will be only 0·05 ohm, and the total resistance will be but 0·15 ohm in the whole circuit. True, the electromotive force will be only 1·6 volts, but by Ohm's law the current in this case will be 10·6 ampères. In the former case the cautery would not be heated, in the latter we should have enough current and to spare. Conversely it is of no use to arrange batteries in parallel when a current has to be passed through a high resistance, such as the human body, a resistance of at least 1,000 ohms, compared with which the internal resistance of thirty or forty cells in series is small.

The coupling of cells in parallel has now lost most of its importance by the introduction of accumulator cells, whose internal resistance is so small as to be a negligible quantity in medical work.

30. **Polarization.**—In former days much ingenuity has been concentrated upon securing constancy of current and absence of polarization in batteries. This is easily seen to be an important matter, for nearly all voltaic cells undergo a fall of electromotive force when any large current is taken from them for any length of time. Polarization of a cell is mainly caused by alterations at the surfaces of the plates of the cell, and chiefly by the accumulation of hydrogen on the positive plate (§ 18), which reduces the available electromotive force of the cell by substituting hydrogen, whose solution pressure is relatively high for copper or carbon, in both of which it is low.

There are other causes which tend to produce a falling off in the current that a cell can give, particularly the saturation of the exciting fluid with zinc ions.

To prevent polarization it is necessary to take some measures that will oppose the formation of bubbles of hydrogen on the positive plate.

In Smee's battery the surface of the silver plate is roughened

by being platinized—*i.e.*, covered with finely-divided platinum—the effect of which is that the bubbles of hydrogen are able to form and escape more easily. When a carbon plate is used its rough surface plays the same part, but it probably acts chemically also by causing oxidation of the hydrogen in the same way that the carbon of charcoal filters causes the oxidation of the organic matter of impure water. Another mechanical method of hindering polarization is to keep the exciting fluid well stirred by forcing air through it or otherwise. None of these methods, however, are so efficacious as the use of chemical means—that is to say, the use of some oxidizing agent in the cell whereby the hydrogen is consumed as fast as it appears on the positive plate. The simplest method of doing this is to add to the exciting liquid some oxidizing compound. This is the plan followed in the chromic acid cell (§ 33) invented by Poggendorf. Another liquid depolarizer that is used is strong nitric acid, but as this attacks zinc violently it is necessary to separate it from the zinc plate, where it would also be unnecessary, by the use of a semi-permeable partition or porous pot, which keeps it in the neighbourhood of the positive plate, where its action is needed, and the battery then becomes a two-fluid battery. In Fig. 6 the arrangement of a two-fluid battery is shown : V is the porous pot containing one liquid and one plate, the other liquid and the other plate standing outside it.

Solid depolarizers may also be used, the one best known being peroxide of manganese, which is used in the Leclanché cell. Oxide of copper has also been employed, while fused chloride of silver is the depolarizer in a battery known as the chloride of silver cell.

31. **Daniell's Battery.**—The oldest and most constant form of two-fluid battery is that known as Daniell's cell. So constant is this cell that it is sometimes used as a standard of electromotive force. Its electromotive force is 1·079 volts, but varies slightly according to the nature and concentration of the solutions employed. A Daniell's cell consists of copper in contact with a solution of sulphate of copper kept saturated by crystals of copper sulphate placed on a shelf near the surface of the liquid, and separated by a porous partition is a zinc plate in contact with a solution of sulphate of zinc acidified with sulphuric acid. Frequently the copper is so shaped as to serve as the containing vessel. The porous partition, while it prevents the mixing of

the two solutions, offers but little resistance to the electrolytic passage of the current. The reactions, then, are as follows: Zinc ions go into solution at the zinc plate, and copper ions go out of solution at the copper plate. Since this latter is already of copper, there is no tendency to polarization here at all, and so

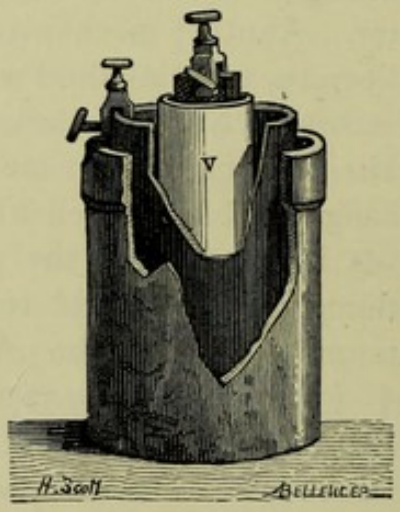

FIG. 6.—TWO-FLUID CELL.

long as the copper sulphate solution is unexhausted there will be no falling off in the electromotive force of the cell, unless from the accumulation of zinc ions opposing the solution of the zinc by osmotic pressure. Daniell's cells might be useful in medical practice for charging accumulators.

32. **Other Types of Cell.**—Grove's and Bunsen's batteries have for their depolarizer strong nitric acid. In the former the positive pole is a platinum plate, in the latter a plate or rod of hard gas carbon. In both batteries the positive pole is contained in a porous pot filled with strong nitric acid, and this is surrounded by the zinc plate contained in a vessel filled with dilute sulphuric acid. The fumes and the corrosiveness of nitric acid form the greatest objection to the use of this battery. It must be taken to pieces and cleaned every time it is used. If it can be set up in a draught cupboard or an outhouse it can be used for recharging accumulators, but the process is a disagreeable one.

The chloride of silver cell was invented in 1868 by Warren de la Rue and Hugo Müller, and modified and improved by Skrivanoff in 1883. The depolarizer is silver chloride fused round a rod or wire of silver, which forms the positive pole of the cell. The silver chloride tends to pass into solution after a

time, and is reduced to metallic silver on the surface of the zinc. Local action then sets in, and the cell deteriorates.

The Lalande oxide of copper cell, as modified by Edison, consists of plates of zinc and copper : oxide of copper compressed upon the copper plate acts as a depolarizer : caustic soda solution is the exciting fluid (Fig. 7). The cells are very constant, and

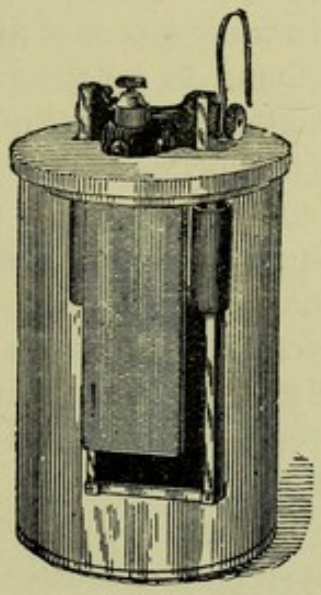

FIG. 7.—EDISON-LALANDE CELL.

can furnish large currents. There is little or no local action. Their electromotive force is low, 0·8 of a volt, and they are not suitable for a portable battery, but might have a use in remote places for cautery work or for charging accumulators.

The sulphate of mercury cell consists of plates of zinc and carbon in a solution of sulphate of mercury.

Latimer Clark's standard cell is a form of sulphate of mercury cell which is used in laboratory experiments, but it requires the utmost delicacy in management, and is used solely as a standard for the comparison of electromotive forces ; its electromotive force is 1·434 volts at 15° C.

The primary cell has lost much of its interest from the introduction of electric light mains and of accumulators, so that almost the only chemical cells which concern the medical practitioner are the Leclanché dry cell, and to a less extent the chromic acid cell.

33. **The Chromic Acid Cell.**—This form of cell is still in use where accumulators or electric light mains are not to be had, and where large currents are required occasionally. Its plates

are of zinc and carbon, and the exciting liquid consists of a solution of potassium bichromate and sulphuric acid. Sodium bichromate has been recommended instead of the potassium salt, as the sodium salt contains, weight for weight, more chromic acid than the potassium salt. A suitable formula is the following: Potassium bichromate or sodium bichromate, $6\frac{1}{4}$ ounces; water, 35 ounces; sulphuric acid, 6 ounces.

The chromic acid cell requires proper attention. If its action fails and the liquid is found to be green in colour it must be renewed. The mixed materials for making fresh solution can be bought in a dry form in bottles. The battery requires to be taken to pieces occasionally, the carbon plates to be soaked in water and brushed with an old tooth-brush, and the zincs to be washed clean and amalgamated. For this they should be scraped smooth and wetted with dilute acid, and then some mercury should be well rubbed into them with a stick of wood wound round at the end with worsted. The surface, when properly amalgamated, looks as bright as silver, and should appear to be wetted by the mercury at every point.

The zincs of this battery must always be removed from the solution immediately after use, and, in fact, should be well cared for and frequently reamalgamated, if the battery is to give the best effect. In medical work the chromic acid cells are now almost entirely abandoned, their place being taken by accumulators for heavy work, and by dry (Leclanché) cells in other cases.

34. **The Leclanché Cell.**—The cell most universally used for medical work is the Leclanché battery (Fig. 8), the exciting solution in which is a saturated solution of ammonium chloride (sal-ammoniac). The electrodes are zinc and carbon. The latter is surrounded by the depolarizer (manganese dioxide), which is able slowly to oxidize the hydrogen evolved by the action of the cell. In the older forms of Leclanché cell the carbon pole is in a porous pot, and is packed round with fragments of carbon and of granular manganese dioxide. Another form of cell has no porous pot, and the carbon has attached to it a conglomerate formed of manganese dioxide and carbon pressed into blocks. In another useful type the carbon and manganese dioxide are enclosed in a canvas sack.

When the circuit is not closed there is no action between the solution and the zinc; but when the circuit is closed the zinc is dissolved, while ammonia and hydrogen are evolved at the

carbon pole. If only a small current is taken from these cells their action is fairly constant, but if much current is used the oxidizing action of the manganese dioxide is unable to keep pace with the evolution of hydrogen, and the cell becomes polarized, though it recovers again when left on open circuit. The advantages of the battery are that it possesses great powers of recovery, has no appreciable local action, and will consequently supply current at intervals for months, or even years, without much attention. Its electromotive force is also fairly high—viz., 1·5 volts.

None of the cells in which dilute acid is used for the exciting liquid can be left to themselves in the same way as the Leclanché,

FIG. 8.—LECLANCHÉ CELL.

for in all of them corrosion would gradually destroy the zinc if it were left in the acid.

Leclanché cells should receive a little attention about once in six months. The larger sizes in glass jars can be easily inspected, and the condition of the zincs and the level of the liquid ascertained.

If the zincs are blackened they should be scraped and amalgamated, and the liquid can be renewed by adding fresh solution of sal-ammoniac. The cells should not be filled to more than two-thirds of their capacity, because it is an advantage that the oxygen of the air may come into contact with parts of the carbon surfaces, and by being condensed there may assist in depolarizing. The proportion of 6 ounces of sal-ammoniac to a pint of water

makes a solution of proper strength. The upper inch of the glass cells ought to be brushed over with vaseline to prevent *creeping* of the salts. This is the formation of crusts of the sal-ammoniac round the top and outer sides of the cells ; it is harmful because it may lead to leakage and waste of current and to corrosion of connecting wires.

When hard crystals form in masses at the bottom of the cell and round the zincs it is time to take down the battery and to set it up afresh. If there is reason to think that the cells are worn out the porous pots may be recharged with manganese dioxide and broken carbon, which can be bought ready mixed, or, better still, they can be replaced by new ones.

The management of the small Leclanché cells used in portable batteries is much more difficult, because it is impossible to see their condition. One can do little beyond emptying out the liquid with a fine syringe, and putting in fresh sal-ammoniac solution in the same way from time to time. In the so-called dry cells this is dispensed with, and the latter are, therefore, more convenient, and they are also cheaper.

35. **Dry Cells.**—These are in many ways exceedingly convenient, and have come into general use for portable medical batteries. They are sealed cells of the Leclanché type, with a

FIG. 9.—HELLESEN'S DRY CELL

pasty instead of a liquid exciting medium. They will work in any position, and require no special attention whatever ; but it must be remembered that the capacity for work of all sealed forms of cell is strictly limited by the original charge of chemicals, and

cannot be restored, when run down, by the addition of fresh exciting fluid. In most of them the zinc plate is shaped like a canister, and forms the containing vessel of the cell; it is lined with a paste of exciting material, and inside this is the carbon and manganese dioxide. Cells of this type are made by the General Electric Company (the E.C.C. cell), by Messrs. Siemens Bros. (the Obach cell and the Hellesen cell), and by numerous other makers.

These dry cells are made in several sizes, the smallest size for portable medical batteries weighing only 8 ounces, and they will last for a year of daily use with proper care, but after that time must be rejected. They cost eighteenpence apiece. Larger sizes are to be preferred for working medical coils.

36. **Accumulators, or Secondary Batteries.** — A so-called *secondary battery* has this property, that when it is run down and exhausted it may be renewed by driving an electric current into it, and thus setting up an electrolysis that brings the plates and

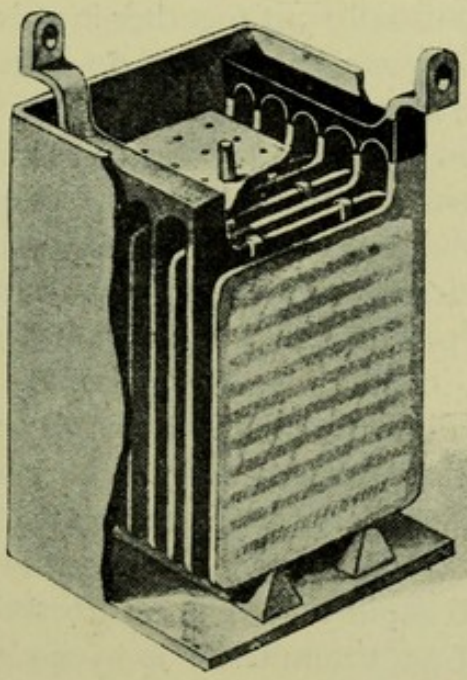

FIG. 10.—ACCUMULATOR CELL, SHOWING ARRANGEMENT OF PLATES.

the electrolyte back to their former state, while in the *primary batteries* it is necessary to renew these. There is no more actual storage of electricity in these batteries than in a primary battery. Either may be looked upon as a store of energy, and in both the energy stored is energy of chemical action.

An accumulator is a vessel containing two sets of lead plates, called the positive and negative plates, and a solution of sulphuric acid of the strength of 1 part of acid to 5 or 6 of water. Each set of plates has a screw connection or terminal for the attachment of wires. In the smaller forms there are usually three plates, one positive and two negative, but there may be five, seven, eleven, or more plates in each cell. Each cell is complete in itself, but for convenience it is usual to arrange four or six cells side by side in one receptacle, and the cells are then connected together in series—that is to say, the positive of one cell to the negative of its next neighbour, and so on, leaving at one end of the series an unconnected positive terminal, and at the other an unconnected negative terminal. The accumulators in common use for medical purposes are made in teak-wood boxes, lead lined, and having partitions to separate the cells.

Convenient small accumulators are also made for use on motor-cars, and these can easily be adapted for medical purposes by the exercise of a little ingenuity. These motor-car cells, or "ignition cells," are usually put together in pairs, and as they are enclosed in celluloid vessels it is easy to inspect the plates at any time in order to ascertain their condition.

Both sets of plates are of lead, but as a result of their mode of preparation their surfaces are dissimilar, the positives being covered with a thick layer of dark chocolate-coloured peroxide of lead, while the negatives are gray from a surface of spongy lead. In many types of cell the plates or "grids" are full of small perforations, containing lead peroxide "paste" in one case, and spongy lead in the other. Positive and negative plates are kept apart by insulators of ebonite, or glass, or celluloid in the form of rods or buttons between the plates. If by accidental movement of the plates a positive should come into contact with a negative, that cell rapidly becomes destroyed.

The chemistry of an accumulator is by no means simple, and it will suffice to state here that during discharge the lead peroxide becomes reduced to lead sulphate. The negative plates also change from metallic (spongy) lead to lead sulphate during discharge. The acid consequently becomes weaker, so that its specific gravity gives an indication of the state of charge in the cell.

The capacity of an accumulator cell varies with the size of its plates, and is expressed in ampère-hours, meaning that it can maintain a discharge current of so many ampères for so many

hours. Thus a 10-ampère hour cell can discharge at the rate of 1 ampère for ten hours, or of 2 ampères for five hours, and so on, and its charging must be in proportion. The charging and discharging current can be measured quite easily with an ampère-meter or ammeter, and the current in ampères multiplied by the time of flow gives the ampère-hours (see caution in § 58).

An accumulator is charged by passing a current into it in the direction from positive to negative through the acid, and when charged it is able to give out a current in the opposite direction, until the energy stored in it by the charge has been expended. The electromotive force of a charged cell is a little over 2 volts, and as the cells in a battery are connected in series, the joint electromotive force of a freshly-charged battery of four cells is 8 volts, or a little over. In practical working the electromotive force is reckoned as 2 volts per cell.

An accumulator may be charged and discharged for an almost indefinite number of times if charging and discharging follow each other at short intervals, but an accumulator tends to deteriorate if left for many days in a charged condition, and deteriorates much more rapidly if left long in a discharged condition.

Accumulators should not be charged or discharged at excessive rates. The proper rates are usually specified by the makers, but are not always adhered to by the users, and this is one reason for the short life of accumulators in careless hands. They should not be fully discharged, but as soon as their electromotive force falls below 2 volts per cell they should be recharged again as soon as possible.

In recharging there is not much danger of injuring them by too prolonged a charge. When fully charged any surplus energy applied is expended mainly in the electrolysis of the acid, though the supports may be attacked if charging is excessively prolonged. A simple way of determining when a cell is fully charged is by auscultation. If a brisk effervescence can be heard the cell is fully charged. A slight effervescence may be heard before the charging is quite complete, and if the charging current is very small the effervescence is not particularly loud even when charging is complete; but a little practice will soon enable a judgment to be formed. There are other methods of determining when a cell is fully charged, but in the case of small medical cells these are more troublesome.

When a cell has just been charged it will be found for a short

time to have an electromotive force of nearly 2·5 volts, but the working voltage is 2 volts. When the cells are discharging the electromotive force is maintained at this point till about 75 per cent. of the charge is expended; after that the electromotive force falls quickly.

It may be taken as a general rule that as soon as the electromotive force of a cell falls below 2 volts, or 1·8 at the lowest, that cell should at once be recharged. If it is not attended to sulphate of lead is liable to encrust the surfaces of the plates, and this insoluble salt increases the internal resistance, and decreases the storage capacity of the cell until at last it may be ruined.

The internal resistance of a storage cell is almost infinitesimal when it is in good order, and may generally be neglected in calculations concerning them, at least in medical work. It is this low internal resistance which makes them so useful for cautery purposes, where large currents are needed.

The difficulties found in working with accumulators of the type having "pasted" plates has caused some makers to return to the original type of accumulator as invented by Planté, where no pastes of the oxides of lead are used.

The lithanode cell is a form of secondary cell which works well, and is made in several different sizes and in portable sets, some of which are admirably adapted for medical purposes. In the lithanode cells the positive plates consist of slabs of a very dense lead peroxide compound enclosed in a metallic framework, and they are free from some of the faults common to the "pasted" plates.

To charge an accumulator from a primary battery, the latter must have an electromotive force greater than that of the cells to be charged. For a two-celled accumulator, five Daniell cells, three chromic acid, or Bunsen, cells, or seven Edison-Lalande cells, are required. The charging cells should be large; the process is as follows: The primary battery having been freshly charged, coupled in series (§ 29), and tested to see that it is in good order, it must be attached to the accumulator, positive pole to positive pole, and negative to negative. Current will then pass to the accumulator from the battery so long as its electromotive force keeps up above that of the secondary cells. The current will slowly diminish as the primary cells run down. When the electromotive forces of the primary and secondary cells are in

equilibrium no current passes in either direction; if the primary cells run down more, the current will set in the other direction, and the accumulator may discharge itself through them, and thus defeat the object of the charging operation.

The operation must accordingly be watched, and stopped before the charging current has fallen to zero. A suitable ammeter (§ 58) will show the magnitude and direction of the current which is passing. By noting the magnitude of current at intervals during the charging process, an idea is obtained of the amount of the charge. For example, suppose the duration of the charge be six hours, and the current during the first hour be 3 ampères, during the second and third hours 2 ampères, during the fourth 1 ampère, and during the fifth and sixth $\frac{1}{2}$ ampère, then the charge will be in ampères for each hour, 3, 2, 2, 1, $\frac{1}{2}$, $\frac{1}{2}$, or 9 ampère-hours.

The Edison accumulator, which may prove of some value in the future, is a cell having for its active materials nickel peroxide and iron. The electrolyte is a solution of caustic potash. Both plates are of nickel-plated steel, with numerous recesses or pockets to contain the active materials.

During the discharge of the cell the nickel peroxide changes to a lower oxide at the positive plate, and at the negative the metallic iron becomes oxidized. During charging the cycle is reversed, and the changes may be represented as follows:

$NiO_2 - KHO - Fe$	$NiO - KHO - FeO$
(charged cell).	(discharged cell).

The plates of the cell appear to act merely as conducting supports, and take no part in the chemical reactions, which are limited to the active materials.

The cells appear to behave remarkably well under trying conditions of all kinds. Irregular charging and discharging do not affect them so unfavourably as is the case with lead accumulators, and they may be left in a discharged condition for a time without injury. On this account they will probably be very suitable for the requirements of medical practice. The working electromotive force of the cell is 1·33 volts.

37. **Magnetism — the Magnetic Field.** — When a magnet is suspended freely at the surface of the earth it is found that it swings so as to set itself with one pole pointing towards the north (or at least approximately so) and the other towards the south.

The poles are spoken of as the *north-seeking* and *south-seeking* poles respectively, and their names are abbreviated into N and S for convenience.

The region of space about any magnet, and throughout which we consider its action, is called its *field*, and lines of magnetic induction or lines of force round a magnet can be mapped out. These will then all leave the iron at points or surfaces indued with N magnetism, and will return to it at points or surfaces indued with S magnetism, and the intensity of a magnetic field at any point will be given by the number of lines of force which cross per unit of surface at right angles to them at that point.

It is easy to map the field of force round any magnet, since every magnet tends to set itself parallel to the lines of force at the point where it is. If then the magnet whose field is to be

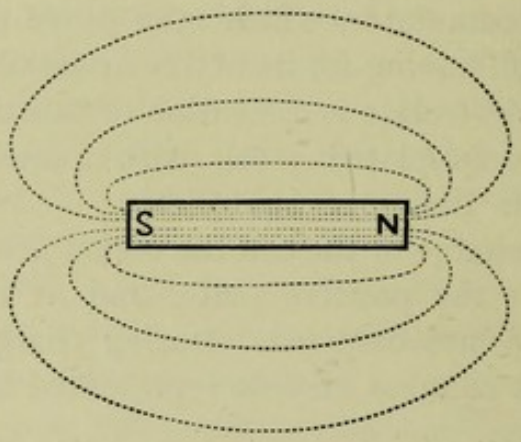

FIG. 11.—LINES OF FORCE OF A BAR MAGNET.

mapped be laid down on a sheet of white paper, and a small compass needle be moved about in its vicinity, the direction of the needle at any point will give the direction of the lines of force at that point, and these can be plotted on the paper. And soft iron filings in a magnetic field set themselves along the lines of force, mapping them out to the eye in a very beautiful manner.

If a sheet of paper be laid down over a bar magnet, and iron filings be sifted over the paper, and the paper be gently tapped, they will arrange themselves into a figure composed of curved lines which emerge from one pole, and pass round to converge at the other (see Fig. 11).

38. **Oersted's Experiment.**—Let a small magnet, say a compass needle, be suspended freely at rest; it will point north and south. Now over it let there be carried a wire joining the two

terminals of a voltaic cell or battery in such a way that its course from copper to zinc along the wire shall be from south to north—*i.e.*, so that the current (the positive direction of flow) is from south to north—then the north-seeking end of the magnet will be deflected towards the west. This observation is due to Oersted, of Copenhagen, and it was formulated by Ampère into a law for telling the direction of flow in a circuit thus : Imagine a man swimming with the current in the wire—*i.e.*, from copper to zinc—and facing the needle, the north-seeking end of the magnet will always be deflected towards his left hand, whatever the position of the wire with regard to the magnetic needle.

From Oersted's experiment we can draw the deduction, viz., that there must be a magnetic field of force about every wire that is carrying a current, and since, when we are facing the magnet and swimming with the current, the N pole is always deflected to the left whatever the position of the magnet with regard to the wire, it follows that the lines of force must pass round the wire in circles, and it is easily shown that they do so by scattering iron filings on a card through a hole in which a vertical wire carrying a moderately strong current is passed. When the card is tapped the filings instantly arrange themselves so as to map out the lines of force as circles round the wire ; also, if we look along the wire from copper to zinc, *i.e.*, with the current, the direction of the lines, the direction in which a N pole will move, is that of the hands of a clock. If a wire be bent into the arc of a circle, when a current passes through this arc there will be a field of force at the centre of the circle, due to the current at all points of the arc. If the arc were in the plane of the paper, and the current ran clock-wise in it, the direction of the lines of force would be vertically down from the paper.

39. **The Electromagnet.** — To illustrate the magnetic properties of a wire carrying a current many devices have been used from time to time as lecture experiments, and some have had important practical applications, as, for instance, the electromagnet and the galvanometer. Soon after the discovery by Oersted of the effect of a current upon a magnetic needle it was found that a wire coiled into a spiral or helix behaved as a magnet when a current traversed it, and the effect became very much more conspicuous if the helix were wound upon an iron rod or core. The explanation of the effect of the iron core is as follows :

Iron conveys magnetic lines more readily than air does, and therefore a given magnetizing current will set up a larger number of magnetic lines when the path for these is either partly or wholly in iron than when it is wholly in air.

In this way Sturgeon constructed magnets of great power, and gave them the name of electromagnets. Since his time electromagnets have had many useful applications, and as the field magnets of dynamo machines they now play a very important part in the industrial applications of electricity. For an account of electromagnets see " The Electromagnet and Electromagnetic Mechanisms," by Silvanus P. Thompson.

Whenever a magnetic field is set up by the passage of a current the growth or formation of the magnetic field is accompanied by an absorption of energy. This energy is not lost, but is stored in the magnetic circuit, to be released again during the collapse or decay of the magnetic field which takes place when the current in the circuit is cut off. A mechanical analogy to this is seen in the storage of energy in a compressed elastic body such as a spring. The energy stored in a spring pistol is recovered suddenly, and often with striking effect, when the pistol is discharged, while in the case of the movement of the springs of a vehicle travelling along a rough road we have an instance of energy stored and liberated in a rhythmic or oscillatory manner.

When a circuit is so arranged as to make the most of these magnetic effects very marked phenomena may be noted, and many electromagnetic mechanisms depend for their action upon the sudden release of stored energy at the moment of rapid decay in a strong magnetic field.

40. **Galvanometers.**—Oersted's discovery enables us to make an instrument for measuring the current in any circuit. Such an instrument is called a *galvanometer ;* or when, as is sometimes the case, it is used merely to indicate the presence of a current, it may be called a *galvanoscope.*

In its simplest form the galvanometer consists of a coil of one or more turns of wire in a vertical plane, with a small magnet suspended or supported freely at the centre. The needle, being free to move, sets itself parallel to the magnetic field that happens to exist at the place where the galvanometer is to be used, and the coils of the instrument are then set parallel to the needle, and therefore to the magnetic field at the place. Hence the field, due to a current circulating in the coils, will be at right

angles to the permanent field with which it is to be compared, and will tend to deflect the needle.

By multiplying the number of turns of wire in the galvanometer coils the action of the current on the needle becomes increased in proportion, each turn exercising its own effect. On this account the name of "multiplier" was once given to the galvanometer. But it must not be forgotten that if the number of windings be largely increased *resistance* is thus introduced, which may have the effect of diminishing the current flowing through the coils. It is therefore necessary to wind galvanometer coils so as to suit the special purposes for which they are intended to be used. The galvanometers used for medical purposes are generally wound with several hundreds of turns. The resistance thus added to the circuit may be considerable, but as the resistance of the body is itself very high, the effect of the galvanometer resistance in diminishing the current is comparatively slight, and is quite unimportant as compared with the advantage gained by the multiplying effect of the turns of wire upon the needle. Thus the small currents used in medical treatment are enabled to produce large deflections of the galvanometer needle.

It must not be forgotten that the deflection of the needle of a galvanometer is not a direct measure of the current circulating in it. Galvanometers must be constructed to suit the special purposes for which they are intended, and some instruments will give considerable deflections with minute or even infinitesimal currents, while others require currents of comparatively huge magnitude to produce even a slight movement of the needle. On this account it is necessary, before comparing the deflections of one galvanometer with another, to be able to express their deflections in current, and galvanometers may be graduated by comparing them with standard instruments. In buying an instrument it is customary to specify the magnitudes of current which it is proposed to measure with the galvanometer required; the instrument-maker is then able to provide a suitable instrument, which has been already graduated to read directly into current.

41. **Measuring Instruments.**—A galvanometer graduated to give readings in ampères is commonly known as an ampèremeter or ammeter. The currents used for medical applications are usually measured in milliampères (§ 25), and the galvano-

meters used are called milliampèremeters. Galvanometers can easily be graduated to give readings in volts, and are then called voltmeters. They are useful when it is wished to measure the electromotive force existing between two conductors at different potentials, as, for example, between the poles of a voltaic cell or battery.

Many devices depending upon the magnetic properties of a wire carrying a current have been adapted for measuring purposes. Similarly, the heating effects of a current, the electrolytic or chemical effects, and the effects of electrostatic attraction (§ 2), have been used in the construction of measuring instruments.

42. **Measurement of Resistance.**—A galvanometer may be used for calculating the resistance of a circuit or of a part of a

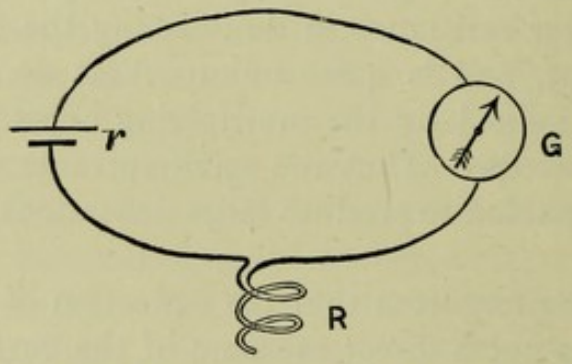

FIG. 12.—MEASUREMENT OF RESISTANCE.
r, Battery; G, galvanometer; R, wire resistance.

circuit. Suppose a Daniell's cell of electromotive force 1·1 volts be connected up through a galvanometer, and the reading of the latter be 0·05 of an ampère, then the resistance of the circuit will be by Ohm's law—

$$R = \frac{E}{C} = \frac{1{\cdot}1}{0{\cdot}05} = 22 \text{ ohms.}$$

The resistance of 22 ohms will be made up of the resistances of the cell, of the conducting wires, and of the galvanometer coils. Now suppose a coil of wire, whose resistance is to be measured, be included in the circuit as in the figure, and the reading of the galvanometer be taken again. Suppose it to be 0·02 of an ampère, then by the same calculation, $R = \frac{1{\cdot}1}{0{\cdot}02} = 55$ ohms, the resistance of the circuit has been increased by 33 ohms, which is the resistance of the coil of wire which was to be measured.

43. **Resistance Coils.**—The method of calculating resistances described in the preceding paragraph is often useful for rough determinations in medical work. In using it we have to rely upon the correctness of the galvanometer, and upon our knowledge of the electromotive force of the battery used. When exact measurements are needed another method is employed by which these elements of uncertainty are avoided, and the resistance is

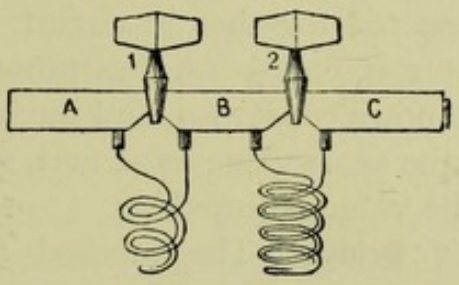

FIG. 13.—PLAN OF RESISTANCE COILS.

measured by comparing it with that of standard "resistance coils." Permanent standard resistances are made from lengths of wire specially wound into coils, and sets of these coils of suitable resistances are sold by instrument-makers in a convenient form. The wires are made of German silver or of some other alloy whose resistance does not change very much with changes of temperature. The coils are enclosed in a box for

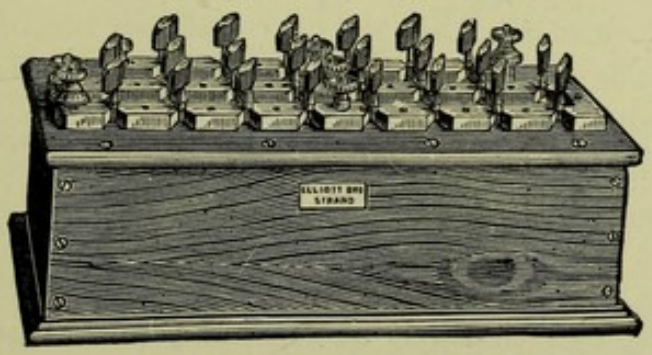

FIG. 14.—RESISTANCE-BOX.

protection, and are connected to consecutive sections of a heavy brass conductor upon the outside of the box, as shown in Figs. 13 and 14. The plugs are used to cut out any of the coils which are not to be included in the circuit. When a plug is inserted the current flows across the plug to the next section, and there is practically no resistance at that point. When a plug is withdrawn the current must pass through the coil. The coils are

arranged in the following order : 1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1,000, 2,000, 2,000, 5,000 ohms respectively. As any of them can be thrown in or out of circuit by removing or replacing plugs on the top of the resistance-box, it will be seen that with the above arrangement of coils any resistance from 1 to 11,000 ohms can be put into circuit. Such a resistance-box can be used to measure resistances by what is called the " substitution method." A battery, a galvanometer, and the unknown resistance are connected together in circuit, and the deflection of the galvanometer is noted. A resistance-box is then substituted for the unknown resistance, and the box is unplugged till the deflection has the same value as at first, when the resistance unplugged gives the value required.

44. **Wheatstone's Bridge.**—The method generally used for measuring resistances is called Wheatstone's bridge method, and consists of an arrangement of conductors as shown diagrammatically in Fig. 15, in which P is a battery having its circuit

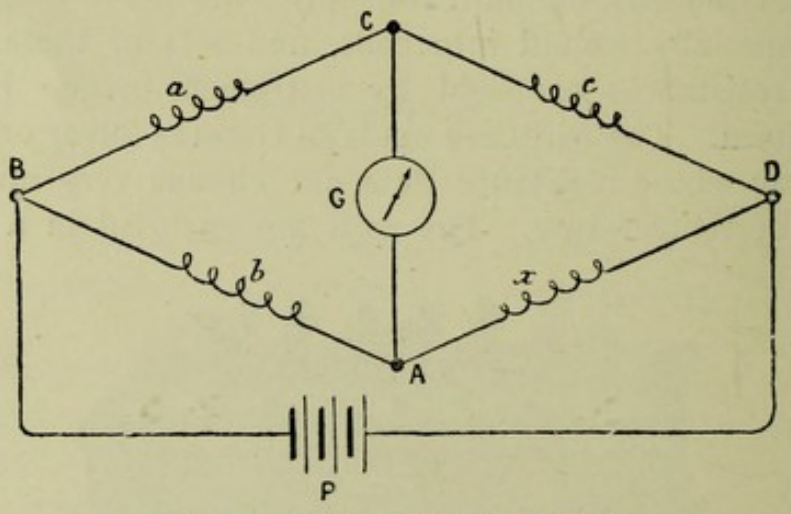

FIG. 15.—WHEATSTONE'S BRIDGE.

divided along two channels at B, and reunited at D, so that part of the current flows through A and part through C. When the current is flowing thus there is a gradual fall of potential along both wires, so that for every point along one there is a point along the other which is at the same potential, and therefore a galvanometer attached to these corresponding points would show no deflection, as there would be no current. If A and C are these points, and *a b c x* are the resistances of the various branches as drawn, when there is no current indicated by the galvanometer we have the relation $a : b = c : x$, and if *a*, *b*, and *c*

are known, the fourth, x, can be calculated from this proportion. The resistance to be tested is joined in between A and D as shown at x in the diagram, and the resistance-box is joined in between C and D. Then, as the simplest case, if the resistances at a and b are equal, the resistances at c can be changed by taking out or putting in the plugs of the box until a balance is obtained, and there is no current through the galvanometer. The sum of the resistances in the arm c is then equal to the resistance of the conductor to be measured. The Wheatstone's bridge method has been much studied and developed, and for details as to the use of the instrument, the various forms it takes, the precautions necessary in working with it, and for a description of the resistance coils, and the way they are wound and adapted, reference must be made to Kempe's "Handbook of Electrical Testing," or other modern textbook of electricity.

45. **Electromagnetic Induction.**—When two distinct circuits are near to each other currents in one will "induce" currents or, more correctly, electromotive forces in the other.

The induced currents are of momentary duration, and appear only when the inducing current is made to vary, as, for example, when it is turned on or turned off. The current induced at the starting of the inducing current is opposite in direction to the inducing current, and the current induced at the break of the inducing current has the same direction as the inducing current. This has been formulated by saying that the induced current is such that the field it would set up tends to neutralize the change in field that is causing it (Lenz's law). These induced currents were discovered by Faraday, and on that account the induced currents employed in medicine are still known as "Faradic currents" among medical practitioners.

In § 38 it was stated that there is a magnetic field of force about every wire carrying a current, and the effects just referred to depend upon the field of force surrounding the wire of the inducing circuit, and generally it may be said that every change of the magnetic condition of the space round a conducting circuit produces an induced E.M.F. or current in the circuit. Thus, the increase or decrease of a current in the inducing circuit, or the approach or withdrawal of the inducing circuit, will change the magnetic conditions round the other circuit, which may be termed the "secondary" circuit, and will set up a current in it. Also, for the same reason, the approach or with-

drawal of a magnetic pole will set up a current in a circuit during the periods of approach or withdrawal, and since the induced current depends upon the variation of the magnetic field in which the circuit is placed, it matters nothing whether the field is caused to vary by moving the magnet or the coil, or by making and unmaking a magnet by any means, or by varying a current in a neighbouring circuit.

The production of electric currents by electromagnetic induction is of enormous practical importance. The commercial developments of electricity rest entirely upon the dynamo machine, which is purely an apparatus for the generation of electricity by the induction effects of magnetic fields upon coils of wire. The importance of the dynamo machine lies in the fact that it affords a means for the direct conversion of mechanical power into electrical power. It does this so simply and efficiently that the primary battery is becoming obsolete as a source of electrical energy, and survives to-day only for minor and special purposes.

46. **Induced Electromotive Force.**—It was stated at the commencement of § 45 that "currents in one circuit will induce currents or, more correctly, electromotive forces" in another. The meaning of the correction is that, although the induction of currents implies the induction of electromotive forces, yet electromotive forces may exist without being able to give rise to currents. An electromotive force can only give rise to a current when there is a conducting path for the current. In the case of a circuit acting inductively upon a conductor near it, the latter would be the seat of a current if it formed part of a closed conducting circuit; but if it did not do so it would be the seat of an electromotive force only, as its circumstances would be against the production of a current in it.

In order to arrive at the magnitude of induced currents we must consider that by Ohm's law (§ 24) this depends upon two quantities, the electromotive force and the resistance of the wire. This latter is constant, since it depends only on the wire; the electromotive force alone varies. Its direction has been already considered; its magnitude is determined by the following law: The total induced electromotive force in any closed circuit is proportional to the rate of change of the number of magnetic lines of force through the space enclosed by the circuit. But the number of lines of force, or, in other words, the strength of

the magnetic field produced by a current in a circuit, is proportional to the current in that circuit. Hence the law may run, "*the induced electromotive force in any closed secondary circuit is proportional to the rate of change of current in the primary circuit.*"

47. **Self-induction.**—When a current is sent through a circuit the magnetic field which is set up round the conductor reacts upon the conductor itself, just as we have seen it do upon a neighbouring circuit, and thus at the moment of completing a circuit the rise of current in it to its proper value is retarded by an induced electromotive force of opposite sign in the wire itself, while when the circuit is broken there is a momentary reinforcement of the current by an induced electromotive force of the same sign as that existing in the wire. This action of an increasing or decreasing current upon its own circuit is spoken of as an action of self-induction, and the reinforcement of the current at the break produced in this way can be amplified and made use of, as will be seen later in the account of induction coils.

The effect which self-induction has of retarding the growth of a current in a wire is not of great importance in the case of steady currents, because the effect is a transient one. In dealing with currents which are in a state of continual variation it is soon found that the matter may be one of very great importance. In the distribution of electrical energy by alternating currents, which is a very common form of electric supply, a consideration of the self-induction of the circuits is absolutely necessary if serious errors are to be avoided.

Conductors supplied with alternating current, especially when they are wound in the form of coils so as to set up strong magnetic fields, are found to have an apparent resistance which is very much greater than they have when tested by steady currents, and the introduction of an iron core into a coil of wire which is carrying an alternating current can easily be shown to produce a still further increase in its apparent resistance. From this it is clear that Ohm's law (§ 24), which specifies that the magnitude of a current in a circuit is determined by two factors only—viz., the electromotive force and the resistance—needs to be modified for the case of varying currents by the introduction into the calculation of a new factor: namely, the self-induction of the circuit. It is the opposing electromotive force, or *back E.M.F.* of self-induction, which increases the apparent resistance.

Sometimes it is convenient to use the expression "ohmic resistance" to signify the resistance of a circuit as measured for steady currents, and to distinguish it from the "virtual resistance" of the same circuit when varying currents are being considered. The word "impedance" is generally used for virtual resistance.

It is very necessary for medical men to have some knowledge of the phenomena of electromagnetic induction, and of the behaviour of circuits carrying varying currents. Without an acquaintance with this part of the subject it is impossible to understand the induction coil, or the construction and management of the various forms of medical apparatus in which alternate currents are used. "High-frequency" phenomena, too, can only be mastered by those who have studied the effects of self-induction and mutual induction. The preceding paragraphs may serve to indicate the importance of the matter, but for a proper elucidation of the laws of varying currents and of electromagnetic effects in general the reader must consult and study a modern textbook of electricity, as, for instance, Silvanus Thompson's "Elementary Lessons," or Fleming's "Alternate-Current Transformer."

48. **The Induction Coil.**—One of the most interesting of the early observations in connection with electromagnetic induction was that shocks and bright sparks could be produced from a single voltaic cell if its circuit contained spiral coils of wire. From the last paragraph we learn that these effects depend upon the self-induction of the circuit, and very shortly after the publication of the researches of Faraday and of Henry in 1831 and 1832 the subject was taken up by others, and coils were made by Page, Sturgeon, Callan, and others, which were the prototypes of the modern induction coil.

The peculiar physiological effect or shock which these induction coils produced soon led to their application to medical treatment, and in 1837 a machine contrived for this purpose by a Mr. Clark was figured in Sturgeon's "Annals of Electricity."* Others quickly followed, and the drawings of the period commonly represent these coils as fitted with handles for patients to grasp, showing the general idea of the mode of employing them in therapeutics. By the introduction of the separate "secondary"

* For an interesting account of the early history of the induction coil, see Fleming, "The Alternate-Current Transformer."

coil, and of the automatic contact-breaker, the induction coil acquired its modern form.

Since then the medical induction coil has undergone many modifications at the hands of ingenious instrument-makers, but few of these modifications have been of much value, because the principles determining the physiological action of the coils have received but scant attention.

It is convenient to consider the phenomena of the induction coil as depending on the variations in the magnetic field of force (§ 38) of a coil of wire in which a current is continually being made and broken. The magnetic field set up in and around the coil at the moment of closing the battery current reacts upon the wire, and produces in it a wave of opposing electromotive force, which retards the growth of the current so that it does not instantaneously reach its full strength, and the collapse of the magnetic field at the moment of breaking the current also sets up a wave of electromotive force in the wire, which strengthens the battery current, and shows itself by a bright spark at the place where the circuit is broken.

In its simplest form an induction coil consists of a single coil of insulated wire wound upon a reel or bobbin with an iron core, and provided with an arrangement, usually a vibrating spring, for automatically closing and opening the circuit. It is connected to a voltaic battery whose current passes through the interrupter. Thus the current is periodically established and interrupted in the windings of the coil, and the magnetic field of the apparatus is caused to vary with every make and break of contact, and currents are induced in the wire coil. The induced current at break can be led off by properly-arranged conductors, and is the "primary current." It is distinct from the battery current. The primary current is therefore a series of impulses or waves all passing in the same direction, and corresponding in time and frequency to the interruptions of the battery current; each wave is due to a sudden rise and fall of electromotive force in the wire, the whole time of each wave being a very small fraction of a second, and varying considerably in different coils.

The secondary current of an induction coil, as its name suggests, is derived from a second entirely independent coil wound upon the same bobbin as the primary coil. Being in the same magnetic field as the primary coil, it is acted upon in the same way, but the effects produced in it are not quite the same. In

the secondary coil there is an induced electromotive force corresponding to the rise of magnetism, and an opposite electromotive force corresponding to its fall. Both of these can give rise to currents through an external circuit, and because they are in opposite directions the currents from the secondary coil are said to be alternating. They are not exactly alike in all respects although the total flux of electricity is the same in each; for the electromotive force set up at the " make " of the battery current is lower, and the duration of the wave is longer, than at the break, because, as has been seen, the rise of the magnetizing current in the primary or inducing coil is more gradual than its fall.

The electromotive forces developed by induction in the primary and secondary coils vary very much in different instru-

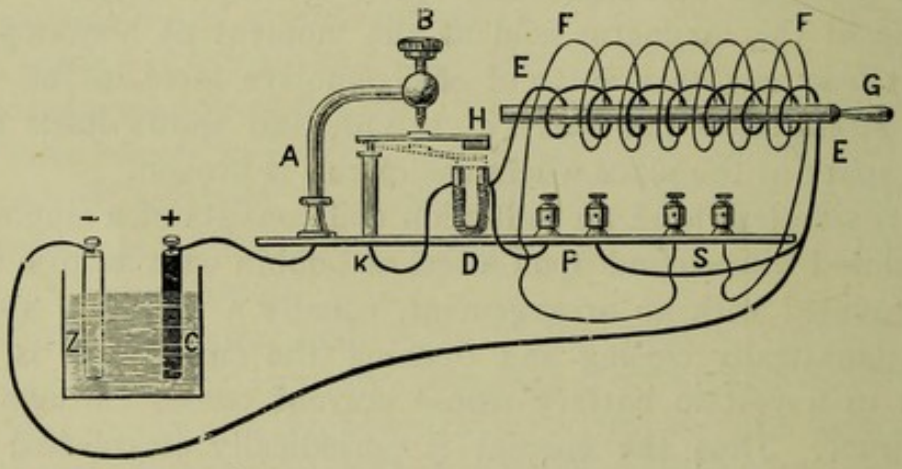

FIG. 16.—ARRANGEMENT OF WIRES IN AN INDUCTION COIL.

ments. In both coils the electromotive forces reach maxima which are higher than that of the battery which supplies energy to the apparatus.

Fig. 16 is a plan of the arrangement of the wires in an induction coil, and Fig. 17 shows an actual coil. The lettering is the same in both of the figures. One pole of the battery is connected to the coil at A. The current then passes by the adjusting-screw B, the vibrator H, and the support K, to a magnet D, which actuates the contact-breaker. After traversing this the circuit gives off a branch to the binding-screw P, and is continued to the primary coil E, E, the return wire from which again gives off a branch to the second binding-screw at P, and is then continued to the other pole of the battery. The two binding-screws at P are thus in connection with the two ends

of the primary coil, and by means of electrodes attached to them the patient may be treated with the primary current of this coil. The secondary coil F is wound on a separate hollow bobbin, and has its terminals at S. This bobbin is made to slide like a sledge on guides, so that it can be made to approach or recede from the primary coil. At G a handle is seen attached to the iron core which can slide in and out of the primary coil, and so further modify the electromotive forces induced in the primary and secondary coils by varying the strength of their magnetic field.

The mode of action of the automatic vibrator or contact-

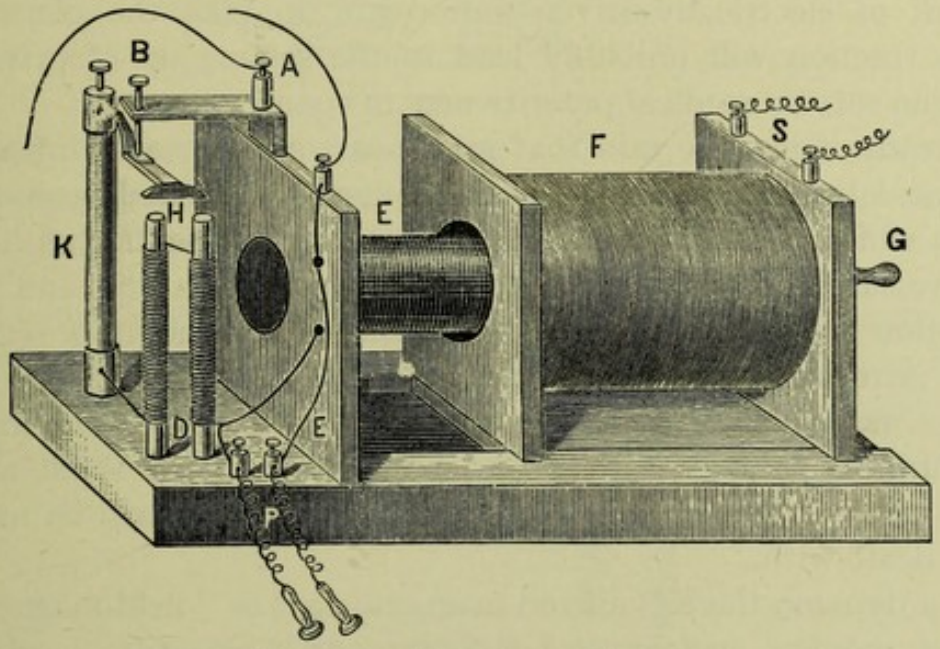

FIG. 17.—INDUCTION COIL.

breaker is clearly shown in the figures. The electromagnet D, by attracting the iron armature H, draws down the spring and breaks the circuit at the point of the screw B, whereupon the attraction of the electromagnet ceases and the spring is released, and flying up, reestablishes the circuit; the action is then repeated, and the spring is kept in constant movement. By turning the screw B the pressure upon the spring and its rate of vibration can be modified. Instead of the separate electromagnet, it is easy to utilize the magnetism of the iron core of the coil for working the contact-breaker, and this is done in those patterns of medical coil which have a fixed core; but in that case some mode of regulation other than that of a sliding core is required.

In order that the coil may be used for medical purposes there must be some method of regulating its strength.

49. **The Dynamo Machine.**—Commercial applications of electricity on a large scale would not be possible without the dynamo, because the primary battery, convenient as it is for some purposes, is altogether unequal to the work of producing electrical currents on a sufficiently large scale. Indeed, there now are many applications of electricity to medical work which require currents of such magnitude that a dynamo or electric light mains are absolutely necessary for them.

In the future there will not only be a further increase of public supplies of electricity for illuminating purposes, but the advent of electrically-driven motor-cars to take the place of horse traction will probably lead to the setting up of private dynamo sets by medical practitioners in country places.

Already it may be said that motor-cars are of use in diffusing electrical knowledge among medical men. The small accumulators which are widely used on motor-cars for electric ignition require care and study if things are to work smoothly, and the attention thus given to the management of accumulators serves as an introduction to the study of electricity for other purposes.

The motor-car accumulator once mastered, its employment for surgical galvano-cautery and lamp instruments is an easy step. In a later chapter its use in medical work will be more fully dealt with.

In a dynamo there is a fixed magnetic part or "field-magnet," and a moving system of conductors or "armature," which rotates in the magnetic field between the poles of the field-magnet.

In the early days of dynamo electric machines the field-magnet consisted of one or more permanent steel magnets. Instruments of this kind still survive, and under the name of "magneto machines" have had a certain vogue for medical purposes. Otherwise electromagnets have now completely superseded permanent magnets for dynamos, and though the shapes seem to vary in different types of machines, all are essentially horseshoe magnets or groups of these.

The field-magnet of a dynamo is an electromagnet magnetized or "excited" by the passage of a current through the coils of wire wound upon it, the current for the purpose being usually taken from the armature of the machine. A slight permanent

magnetism exists in all field-magnet cores, and this is sufficient to start small currents in the armature when it is rotated. These currents are made to traverse the windings on the field-magnet, and they strengthen it so that it reacts more strongly

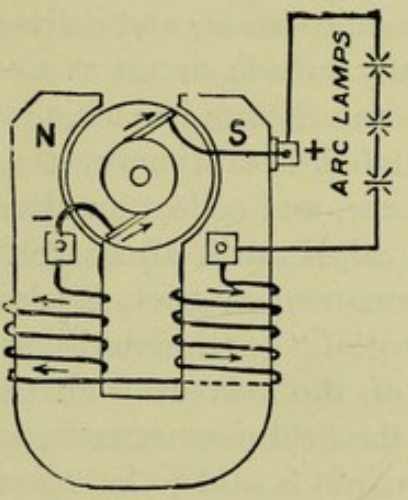

FIG. 18.—SERIES-WOUND DYNAMO, WITH THREE LAMPS, ALSO IN SERIES, IN EXTERNAL CIRCUIT.

on the armature, until by the continuance of this mutual reaction between the armature and the field-magnet the latter becomes fully magnetized. Thus a dynamo is a self-exciting machine. The armature is mounted on a shaft provided with a pulley for

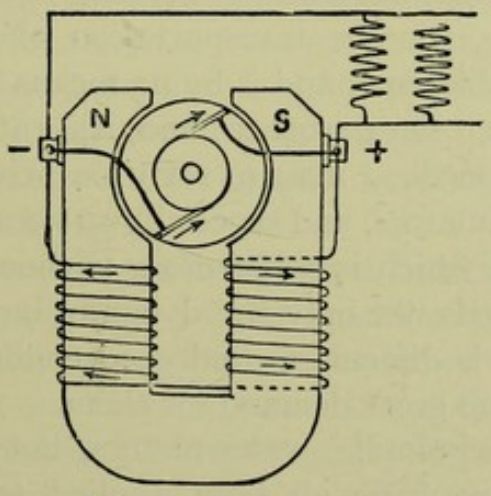

FIG. 19.—SHUNT-WOUND DYNAMO, WITH TWO RESISTANCES, ALSO IN SHUNT, IN OUTER CIRCUIT.

the purpose of rotation, and at one end of it is fixed the commutator, which is built up of a number of copper or brass segments insulated from the shaft and from each other ; the ends of the coil or coils of wire which form the armature are connected

to a pair of these commutator segments, and when the armature is in rotation the segments pass in turn under the ends of two collecting-brushes of metal which make contact with them.

The commutator is a necessary part of a continuous-current dynamo, for it serves to rectify the alternate currents generated in the coils during their rotation, and delivers them to the field-magnet coils and to the outside circuit as a continuous current in one direction. In some dynamo machines the commutator is replaced by two insulated metal rings on the shaft. The collecting-brushes touch these, and collect an alternating current, and such a dynamo is called an "alternator." Its field-magnet must either be a permanent magnet, or else it must be excited from a separate source of "continuous" current.

When the whole of the current from the collecting-brushes passes first through the field-magnet coils, and then through the outer circuit, the dynamo is said to be "series-wound," the two portions of the circuit being in series, whereas a "shunt-wound" dynamo has the field-magnet coils in parallel or in "shunt" with the outer circuit (Figs. 18 and 19). Each of these windings present advantages for certain purposes.

50. **Power for Dynamo-driving.**—Chemical batteries are of no use as a source of current in the magnitudes and at the pressures needed for much of the electrotherapeutic work of to-day. In the absence of a public lighting supply a dynamo is almost a necessity, for the transportation of accumulators is expensive and troublesome, and is by no means conducive to the long life of the cells. On the other hand, it is rather a formidable undertaking for a medical man to set up a private dynamo for charging his accumulators, and especially so because it is difficult to procure a plant which is satisfactory without also being too big. Then one needs not only the dynamo, but also the power to drive it, and it is difficult to find good engines of very small power, as there is no great demand for them.

Manual power, windmills, water-motors, hot-air motors, and gas and oil engines, have all been applied to the driving of dynamos. In any particular case the local conditions will help to decide which is likely to be the most convenient source of power. In charging an accumulator from a dynamo the electromotive force of the charging source must be maintained steadily above that of the cells to be charged, for if this is not done the cells will discharge back through the dynamo, with a result quite

opposite to that desired. On this account manual power is too unsteady for serious purposes. A fairly useful apparatus for dynamo-driving has been contrived by adapting a bicycle, and so making use of pedal power, and it is interesting to note that electricity for charging accumulators for Roentgen-ray work in the Soudan campaign was generated by means of an apparatus of this kind, a tandem bicycle being so converted as to drive the dynamo by means of a belt from the hind wheel. (See the illustrated paper by Surgeon-Major Battersby in the *Archives of the Roentgen Ray* for February, 1899.)

In some places a small windmill might be of use for charging a few storage cells, and where there is a cheap water-supply a water-motor gives little trouble and would be a useful contrivance, but these instruments consume much water. Several forms of these are made in small sizes, and can be had from the makers of physical apparatus.

Many makers now list small gas-engines of one-eighth or one-quarter horse-power, which can be used to drive a dynamo for charging storage cells. These would probably answer for charging purposes quite well in the hands of anyone who was willing to take some trouble to understand them thoroughly. The Pittler Company (144, High Holborn) list a one "man-power" gas-engine at nine guineas. In the larger size of one-half horse-power one begins to reach practical and good gas and oil engines. The Gardner engines,* for gas and oil, cost £15 and £25 respectively at this power, and can be specially provided with dynamo, pulleys, belts, etc., complete, for about £10 more. With one of these sets the charging of storage cells can be effectively dealt with.

When charging an accumulator from a dynamo the possibility of an unexpected stoppage of the machine must be borne in mind. To meet this possibility automatic switches have been contrived which at once cut off the cells from the dynamo circuit if anything goes wrong. This is necessary to prevent the charge already accumulated in the storage cells from running down through the dynamo circuit, to the probable damage both of dynamo and cells. A shunt-wound dynamo must be used for the purpose of accumulator-charging.

51. **Motors.** — The direct-current dynamo is a reversible machine, inasmuch as it can act as a motor if supplied with

* Norris and Henty, 87, Queen Victoria Street, E.C.

current from an external source. In this case it converts an electrical current into mechanical power, whereas when used as a dynamo it converts mechanical power into an electrical current.

Motors, like dynamos, may be either shunt-wound or series-wound. Motors have certain applications in medical work. The shunt-wound motor admits of better speed regulation than the series form. Small motors may easily be destroyed at starting if care be not taken to start with the safety resistance properly adjusted, and the little shunt-wound motors used for operating interrupters for induction coils and other medical purposes are often spoiled through such inattention. In buying a motor it is necessary to specify the pressure of supply (in volts) from which it will be driven, the amount of power (in horse-power or fractions of a horse-power) it will be expected to exert, and, in the case of alternating-current circuits, the periodicity of the alternations must also be mentioned. Motors for use on alternating circuits are more complex machines than are direct-current motors. For an account of their construction, their advantages and disadvantages, special engineering textbooks must be consulted.

The character of the electrical supply in the different electricity supply works in the United Kingdom will be found in the Appendix. There a list is given of towns having a public supply of direct or of alternating current, with particulars of the pressure of supply and, in the case of alternating current, of the periodicity of the alternations.

52. **Alternating Currents.**—The system of distribution of electrical energy by alternating currents is a very general one, and is in use in nearly a hundred towns and places in the British Islands.

An alternating current is one which rises from zero to a maximum, and falls away again, to be followed immediately by a reversed current, which also grows to a maximum and wanes in the same manner. When a closed coil or circuit of wire is rotated in a magnetic field the wire is traversed by an alternating current of this kind once for every complete revolution of the coil, and this recurs again and again as often as the coil is rotated, giving one cycle or period for each revolution.

Each cycle consists of two semi-cycles which are equal and opposite; the one corresponds to the passage of the coil through lines of N magnetism, and the other to its passage through lines of S magnetism.

The changes in value of any regularly varying quantity, as, for example, electromotive force or current, can be represented graphically by a curved line, just as the variations in the body temperature of a patient are recorded upon the temperature charts used in clinical work.

If a horizontal line be drawn to represent periods of time, and if magnitudes of electromotive force be represented by distances above the base line (positive) or below it (negative), then an electromotive force gradually rising from zero to a maximum of 15 volts positive, and falling again, could be represented by the curved line A, B, C (Fig. 20), and the continuation of the curve C, D, E represents a reversal in sign of the electromotive force, with a fall to 15 volts negative, followed by a return to zero, the

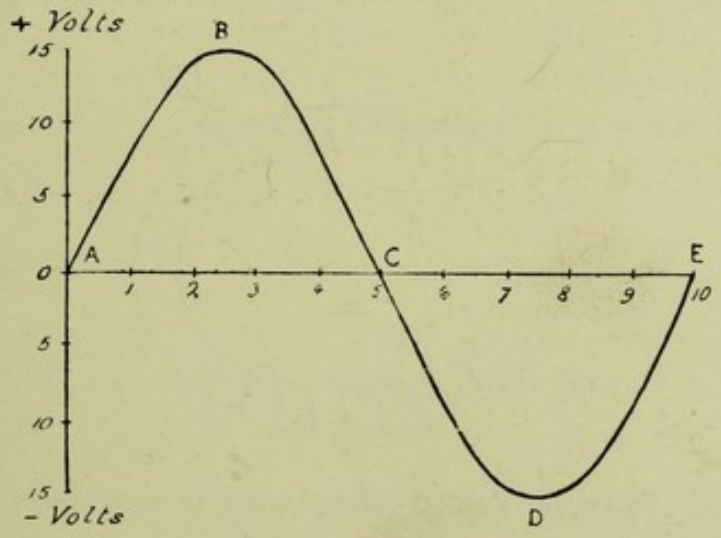

FIG. 20.—GRAPHIC REPRESENTATION OF A STEADILY-VARYING ELECTROMOTIVE FORCE.

period of time of the whole cycle being represented by the base line A, E. Similar curves could clearly be drawn to represent any values of a varying electromotive force or current, and any periods of time.

When the shape of the curve is known the electromotive force at any instant can be readily determined by plotting out the curve upon paper suitably ruled with lines (squared paper), and, conversely, curves can be constructed by observing a sufficient number of instantaneous values and marking them out on the paper.

The curve in Fig. 20 represents the gradual rise and fall of the electromotive force from an alternate-current dynamo machine, and may be taken as approximating closely to the current curve

of an alternating system of electric light supply, and with such a curve the ratio of maximum to mean electromotive force is as 1 to 0·637, or as 1·57 to 1, if the mean be taken as unity. A curve of this kind is known as a simple periodic curve or a sine curve, and the current from an alternating-current dynamo is often spoken of as a *sinusoidal* current, to signify that it approximates in its wave form to a true sine curve.

The "frequency" of an alternating current or its "periodicity" means the number of periods or cycles occurring in one second.

53. **The Transformer.**—One great convenience of alternate currents is the ease with which they can be made to induce fresh alternating currents at a different voltage. With continuous currents the pressure of supply can be cut down by resistances, but by means of a transformer the pressure of supply of an

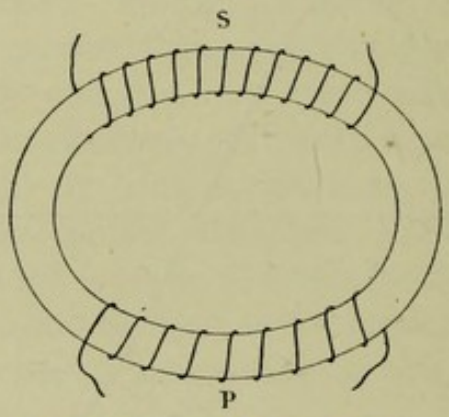

FIG. 21.—PLAN OF TRANSFORMER WITH CLOSED IRON CIRCUIT.

alternating current can be changed into any other pressure, higher or lower, as may be desired, and that without the waste of energy which occurs in the case of resistances. Thus the energy represented by a current of 1 ampère at 100 volts can be transformed into a current of 100 ampères at 1 volt, or into a current of $\frac{1}{100}$ ampère at 10,000 volts, subject only to small losses in the apparatus. Whenever the pressure of the alternating-current mains is higher than may be required in medical applications it can easily be reduced by the use of a transformer, and this should always be borne in mind.

The principle of the transformer is that of the induction of a current in a wire immersed in a varying magnetic field. A transformer consists of an iron core wound with two distinct windings of insulated wire, and thus resembles an induction coil; but no interrupter is required to produce the variations in current,

as these exist already in the alternating current supplied to the transformer. The two sets of windings are called the primary and the secondary windings, and the alternating current supplied to the primary when it is connected to a system of alternate-current supply will set up a varying magnetic field, which will induce in the secondary a varying electromotive force, whose value will depend upon the ratios of the number of turns of wire in the two coils. The coils may be wound one over the other upon a straight iron core, just as is done in an induction coil, when it is spoken of as a transformer with an open magnetic circuit, or the iron core may be in the form of a ring or rectangle, with the two coils wound upon it at different points. It is then said to have a closed magnetic circuit, as the magnetic flux set up by the current in the primary winding has a continuous path in iron for the whole of its circuit. By reason of the superiority of iron over air for the magnetic lines of force there will be an advantage in giving this shape to the iron core.

CHAPTER II

MEDICAL BATTERIES AND APPARATUS

The continuous current—Commutators—The galvanometer—Interrupted currents—Medical coils—Other apparatus for interrupted currents—Resistances—Rhythmic interrupters—Electrodes—Arm-bath electrodes—The electric bath.

54. **The Medical Battery.**—This term is used to signify an apparatus for the production of current for medical purposes, and it includes several distinct forms of instrument. One of these is an arrangement in a suitable box of a number of small voltaic cells coupled together in series, and having a contrivance or "current collector" for varying at will the number of cells taken up into circuit with the patient.

It is also fitted with attachments or terminals for wire conductors, and should further possess a current reverser or "commutator" and a galvanometer. Such an instrument is usually spoken of as a continuous-current battery, to distinguish it from the interrupted-current battery, in which an induction coil with one or more cells for driving it takes the place of the cells grouped in series. These various fittings are fastened to a plate of ebonite, which is fixed above the cells in the box (see Figs. 22 and 23). The induction coil also requires some means for regulating the strength of the current, but the galvanometer affords no useful indications with the form of current given out by the induction coil.

Special batteries are also made for furnishing current for galvano-cautery instruments and for the operation of exploring-lamps, and these will require description in their proper place.

The distinction between continuous current and interrupted current is an important one in most of the applications of electric currents to patients.

The terms "continuous current," or "constant current," or "galvanic current," are applied to the current of the cells of the

battery, and the current furnished by the induction coil is known as the interrupted or faradic current. The current from the cells of the battery flows through the circuit in one direction from the positive to the negative terminal so long as the circuit is closed, and if the resistance of the circuit remains unchanged its strength

FIG. 22.—COMBINED MEDICAL BATTERY, SHOWING CURRENT COLLECTOR, GALVANOMETER, COMMUTATOR, AND SWITCH.

R, N, current reverser (see Fig. 27). G, F, switch for changing over from continuous to interrupted current, and *vice versâ*. The induction coil is on the left beneath the surface, but the handles for regulating its current are seen projecting. P, S, switch for primary and secondary currents of coil.

is uniform, and when the circuit is broken by removing the electrodes from the patient or by opening a key, the current ceases abruptly. If the electrode be caused to slide over the surface of the body there will be variations of strength in the neighbourhood of the moving electrode, for the point of entry of

the current, or point of greatest density of flow, will vary in position, even though the total current flowing in the circuit, as indicated by the galvanometer, be steady and uniform.

Thus the " continuous " current may be applied either in the form of a steady flow, as its name would naturally imply, or in a series of impulses produced by the operator by means of some circuit-closing or circuit-opening device ; or, again, the current through any particular part can be made to vary in a gradual manner by means of the sliding movements of the electrodes, as

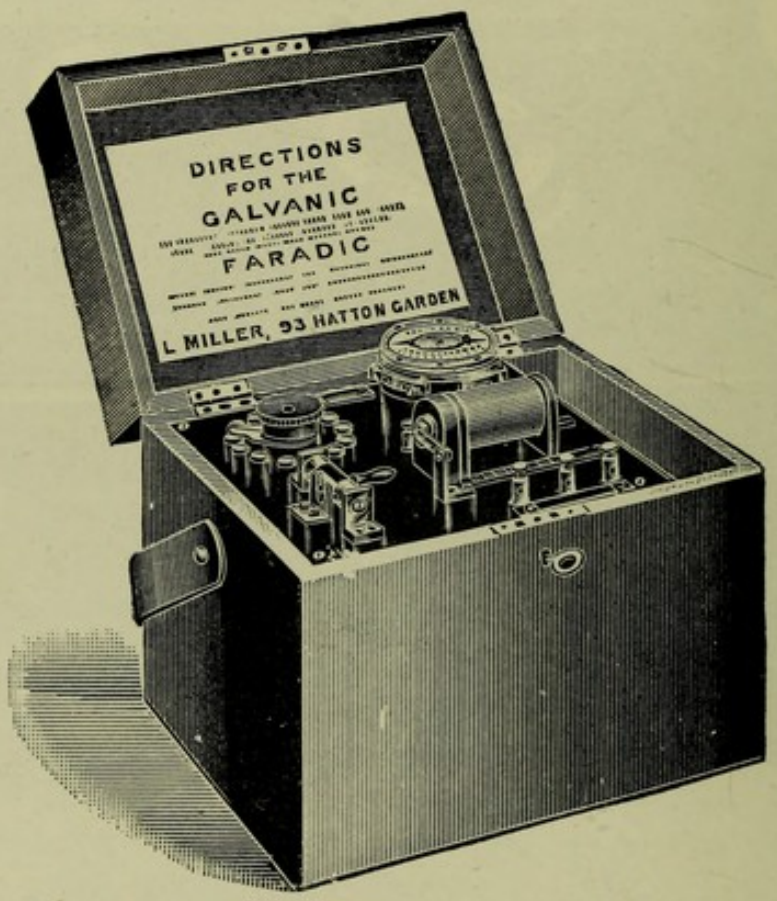

FIG. 23.—COMBINED MEDICAL BATTERY.

already described. In all of these forms it is still spoken of as the continuous current for purposes of convenient description, and to distinguish the current of the cells from that of the induction coil.

It is very often useful to combine the instruments for continuous and interrupted currents in one case, and such an arrangement is called a " combined battery." These combined batteries are in very general use, and are made and sold by all instrument-makers who deal in medical electrical apparatus. Figs. 22 and 23 illustrate two useful forms of combined battery.

Although it is in many ways a convenience to have the coil and the battery of cells combined in one instrument, the medical man is likely to find it convenient to have a separate portable induction coil, as the possession of such an instrument may sometimes obviate the need for carrying about a heavy combined battery. So, too, one may obtain simple batteries of cells for continuous currents, which are often useful when it may be desired to lend a battery to a patient. For details of these batteries the instrument-makers' catalogues should be consulted.

Although they may differ somewhat in the arrangement of their parts, medical batteries are constructed upon the same general lines, and when one has become familiar with the batteries of one instrument-maker it is quite easy to identify the working parts of other makers' instruments.

55. **Current Collectors.**—A continuous-current battery may contain a large number of cells (20, 30, or upwards arranged in series), but the number of cells to be used in different cases varies very much. On this account a ready means of altering the number of cells in circuit is required so that the current may be readily increased or diminished to suit the needs of each case. The plan is as follows : A circle of studs is fitted

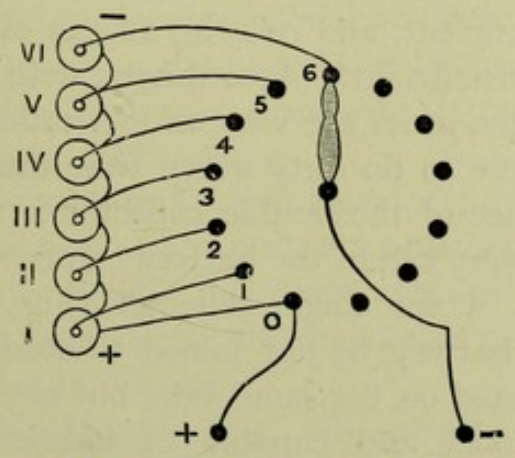

FIG. 24.—PLAN OF A SINGLE CURRENT COLLECTOR.

to the ebonite plate which overlies the cells in the box, and wires are led to these studs from the corresponding cells beneath. A moving arm can be turned so as to make contact with any of the studs, and then leads off the current from the stud which it touches.

In the diagram, Fig. 24, six cells are shown numbered I. to VI. ; they are joined in series, and from the terminals wires are

led off to seven corresponding studs numbered 0 to 6. It may be seen that a movable metallic arm springing on to stud No. 1 will throw one cell into circuit between the binding-screws, marked + and −, and similarly when the arm is placed on any other stud it brings into the circuit the number of cells shown by the figure marked against the stud.

The stud marked 0 is connected with one pole, say the positive pole of cell No. 1, and leads to a binding-screw marked +, stud No. 1 being attached to the negative pole of the same cell. When the movable arm touches stud No. 1, the current passes along it, and from there goes to the other terminal of the battery, as shown in the figure. Cell No. I. only is then included in the circuit; if the pointer be transferred to another stud, numbered, let us say, 6, then six cells are in circuit and are being used.

A more complicated current collector has been devised, by means of which the current may be taken from any cell or any group of cells commencing at any point. In the single collector the first cells are always drawn upon, and are likely to run down before the last cells, which are only needed occasionally. With the double collector, if six cells are required, not only could cells 1 to 6 be chosen, but cells 4 to 9, or 7 to 12, or 13 to 18, or any other set of six. With the single collector the first cells must always provide current, and cell No. 12 can only be used when eleven cells are insufficient. Accordingly, with a single collector the last cells of the series are very seldom called on at all, while the first cells have to do duty every time the battery is used. Another advantage of the double collector is that with its aid the working of every cell of the battery can be separately tested. If in the figure of the single collector (Fig. 24) the positive terminal of the battery be not joined to stud No. 0, but to a second arm, pivoted on the same axle, but electrically insulated from the first one, and capable of independent movement (Fig. 25), and if this second arm be joined to the positive terminal, it can be seen that with the two arms on the studs 3 and 6 the current would be taken from cells 4, 5, and 6 only—that is to say, the group of cells 4 to 6 would supply the current to the circuit. In like manner any number of consecutive cells from one upwards could be picked out from any part of the whole series. It is usual for one of the arms to carry a circle so divided and numbered as to read off directly the number of cells in use.

The studs of current collectors must be of good size, and the pointer just broad enough to touch two at once, in order that the number of cells in the circuit may be increased or diminished without breaks of current and unpleasant shocks at the change from one stud to the next. At the same time care must be taken that the movable pointer of any collector is not left for

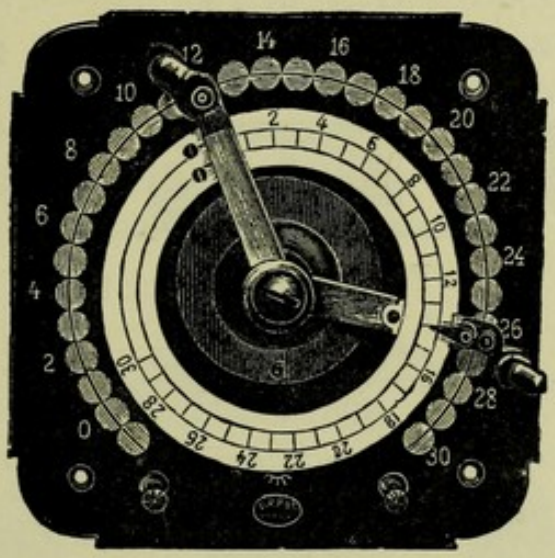

FIG. 25.—DOUBLE COLLECTOR.

any length of time in contact with two studs at once, for when it is in that position one cell is short-circuited, and its energy is being wasted. This waste can be reduced by the use of a collector having a longitudinally divided arm, with its two portions joined through a resistance of fifty ohms.

56. **The Commutator or Current Reverser.**—An apparatus for reversing the direction of the current in the external portion of the circuit is indispensable for some medical purposes. It is difficult to make a satisfactory examination of the reactions of nerve and muscle without one.

Ruhmkorff's commutator (Fig. 26) consists of a cylinder of vulcanite M, having at each end a metal cap or ferrule, C, D, and supported between two uprights in such a way as to revolve easily about a horizontal line; each end is connected to a binding-screw A, B, and each metal cap is prolonged in the form of a cheek, E, F, along one side of the vulcanite cylinder for two-thirds of its length. On either side of the cylinder, springing against it, are two pieces of metal I and L, connected with the terminals of the battery. When the cylinder is turned by means of the handle Z, either of the metal cheeks can be brought into

contact with each of the springs, I, L. The positive pole of the battery connected, say with L, can thus be brought into connection with either the binding-screw at A or at B, so that the current can be made to pass in either direction at will round the external portion of the circuit between A and B. The + and

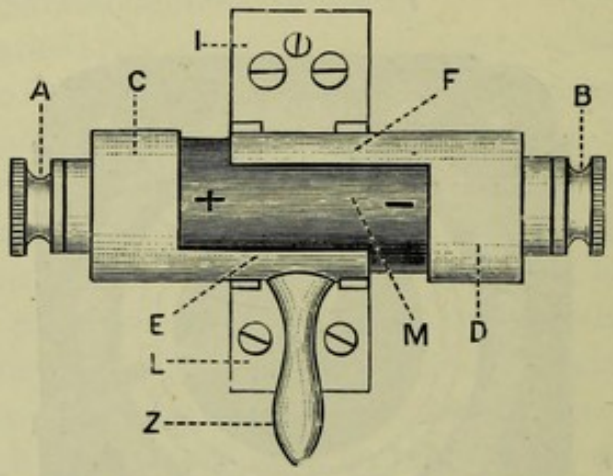

Fig. 26.—Commutator of Ruhmkorff.

− signs on the vulcanite cylinder indicate the polarity of the binding-screws. In the position shown A is positive; a half revolution of the cylinder alters A to negative, and therefore the reverse side of the cylinder, which then comes into view, will have the + and − signs transposed also.

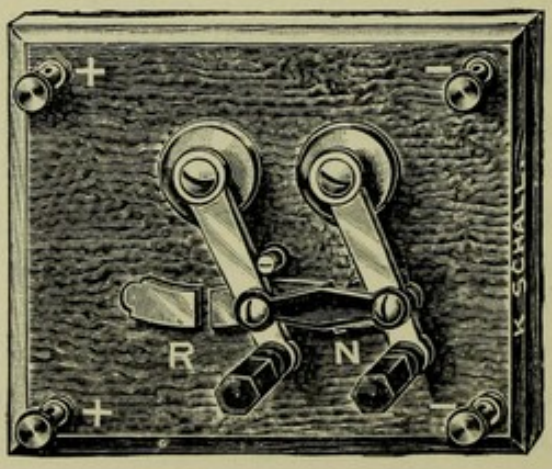

Fig. 27.—De Watteville's Commutator.

Another form of commutator is shown in Fig. 27. In this the two crank arms move together. In the figure N stands for normal, R for reversed.

57. **Galvanometers.**—The older types of galvanometer are being superseded in medical practice by newer forms of instru-

ment of the d'Arsonval pattern, or of some modifications of it. These have the advantage that they can be used either in a horizontal or vertical position. They are independent of the earth's magnetism, and therefore do not require to be set in the magnetic meridian, nor are they affected by the proximity of iron or of stray magnetic fields in their neighbourhood. They are also dead-beat—that is to say, the pointer indicates its readings without preliminary oscillations. Thus time is saved, and the patient spared the inconvenience of having to bear a possibly painful current while the operator is waiting for the oscillations of the needle to settle down, in order that he may obtain a reading of the milliampèremeter.

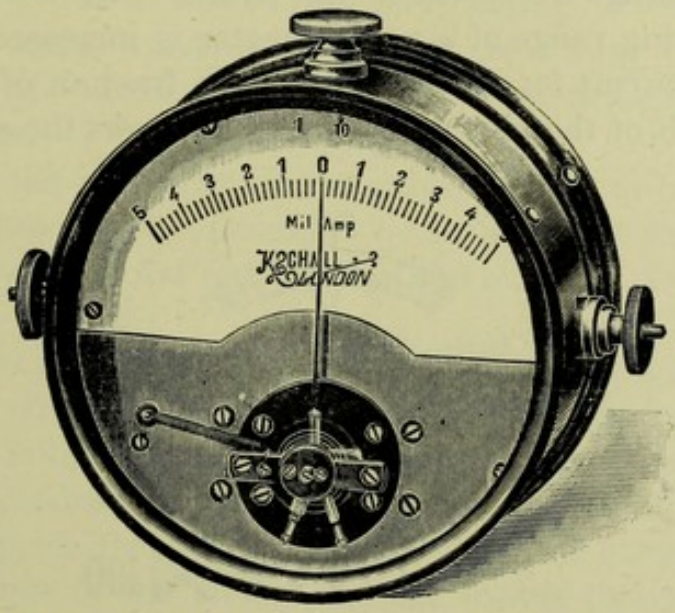

FIG. 28.—D'ARSONVAL MILLIAMPÈREMETER, WITH MOVING COIL.

In the d'Arsonval instruments the movements of the needle are controlled by placing it in a strong magnetic field between the poles of a horse-shoe magnet. In the modified "moving-coil" instrument the magnetic needle is replaced by a slender coil of wire which carries the current, and so acquires magnetic properties (§ 38). It is so suspended as to be free to move, and a spring attachment brings it back to zero again. The general appearance of these instruments is shown in Fig. 28. They may be obtained as milliampèremeters, as voltmeters, and as ampère-meters, and can be constructed to read within any range likely to be required in medical practice.

In the case of horizontal galvanometers of the ordinary type, the position which the needle takes up when a current is flowing

through its coils is the resultant of two forces—viz., the attraction of the earth's magnetism tending to hold the needle in the magnetic meridian, and the attraction of the field of force of the coils tending to draw it into a position at right angles to this. Changes in the magnetism of the needle do not alter the relation which the two opposing pulls bear to one another, and therefore the deflections of the needle are not altered if the magnetism of the needle becomes diminished, as may be the case with the lapse of time. This makes the horizontal galvanometer trustworthy for use as a standard instrument.

Before use all horizontal galvanometers must be so placed and levelled that the needle comes to rest at the zero of the scale, and swings freely about that point.

The working range of a galvanometer is increased by the use of a shunt circuit for diverting a known fraction of the current from the coils of the instrument. Fig. 29 shows the arrangement.

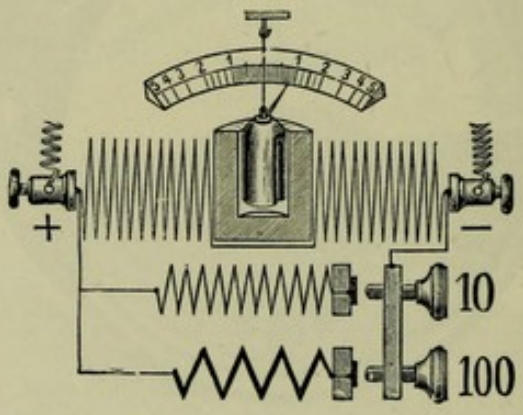

FIG. 29.—PLAN OF SHUNT CIRCUITS OF A GALVANOMETER.

Between the binding-screws, marked + and −, the galvanometer coils are represented. Two other paths are shown beneath, either of which can be completed at the points of their respective screws; both of them have a lower resistance than the circuit of the galvanometer coils, and when closed they convey nine-tenths and ninety-nine hundredths respectively of the current, while the remaining tenth part or hundredth part traverses the galvanometer coils and produces its proper deflection. But if the deflection is known to be due to one-tenth of the current only, then to get the total current the indicated reading must be multiplied by ten, and the same for the other or 100 times shunt.

Both shunt circuits are not to be closed at one time.

By means of a battery and a resistance-box it is easy to verify the readings of a galvanometer, and to determine whether the shunts work correctly.

58. **Ammeters and Voltmeters.**—Ampèremeters or ammeters are sometimes needed by medical men for measuring larger currents than those for which milliampèremeters are used. In general an ammeter has a very low resistance, and must not be coupled direct to the terminals of an accumulator or to the main supply. If this is done the instrument may be destroyed at once. The proper way is to connect it in series with the instrument or apparatus the current through which it is required to measure.

Voltmeters, on the other hand, generally have a high resistance, which protects them from overheating unless they are misused. A very convenient way of measuring the electromotive force of a medical battery is to use its own galvanometer as a voltmeter.

Supposing the resistance of the galvanometer to be 25 ohms, and a resistance coil of 975 ohms to be connected to the terminals of the battery, the total resistance in the external circuit will be 1,000 ohms.

Now, one volt acting upon a resistance of one thousand ohms will cause a current of one-thousandth of an ampère to flow—that is to say, one milliampère. With five volts, five milliampères, and so on. The readings of the galvanometer in milliampères will, therefore, express the electromotive force of the battery in volts if the resistance of the circuit amount to one thousand ohms; any correction for internal resistance of the cells themselves may usually be disregarded. This method has the advantage of measuring the electromotive force under conditions of resistance like those for which the battery is to be used.

Instrument-makers can usually supply a resistance coil properly wound to bring up the total resistance of the galvanometer circuit to a thousand ohms, in order to simplify this mode of measuring the electromotive force of the cells of a medical battery. With this it is very easy to test the voltage of the individual cells, by taking readings of the galvanometer while switching on the cells one after another. Each cell may be taken separately if the battery have a double collector (§ 55); if it have a single collector, the increase of reading for each cell added may be taken to represent its electromotive force. If the resistance coil available do not bring the resistance of the circuit

to so simple a figure as 1,000 ohms, the method can easily be used by applying a simple calculation based on Ohm's law.

The expansion of a wire when heated by the passage of a current may be used as a measure of the current, or by suitable graduation of its scale it may be made to read directly in volts. Cardew's "hot-wire" voltmeter consists of a platinum-iridium wire which is heated by the current, and expands, thus moving a pointer which indicates the expansion on a specially calibrated dial.

Fig. 30 shows the construction of a "hot-wire" instrument. C is the wire stretched between H and K by a spring F. A

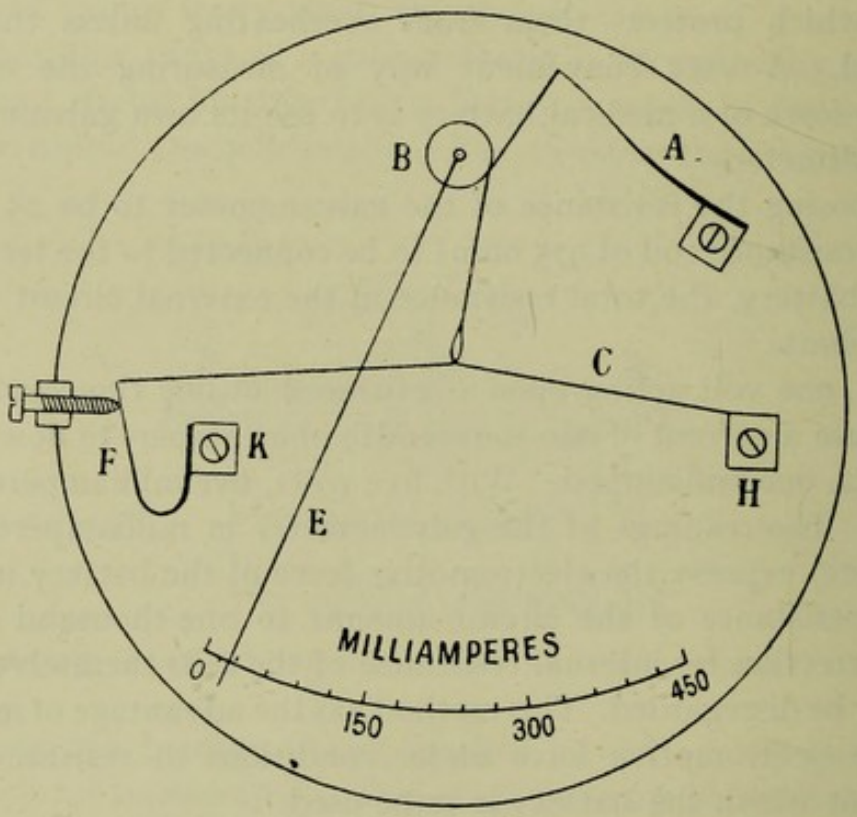

FIG. 30.—ARRANGEMENT OF "HOT WIRE" INSTRUMENT, CALIBRATED AS A MILLIAMPÈREMETER.

thread attached to its centre passes round B to a spring A. When the wire expands the pull of A deflects it, and the movement is communicated through B to the pointer E.

59. **Interrupted Current.—The Medical Coil.**—In medical practice the induction coil has been universally adopted as the source of interrupted currents, but it is necessary to point out that the current of an induction coil is a special form of interrupted current of some complexity. The coil is useful because it

affords a convenient means of producing sensory and motor effects at small cost. For purposes of stimulation it serves admirably, and in so far as electrical treatment consists in the simple stimulation of living tissues the induction coil is a most valuable appliance. Its use for accurate work, however, has the drawback that induction-coil currents vary much in character, while their measurement is impossible in practice with any certainty.

The variety of coils in the market is very great. Usually they are fitted up in a box with one or two dry cells to drive them, and with a drawer to hold wires and electrodes; this is convenient, as it makes them portable. An inspection of an instrument-maker's illustrated catalogue, or better still of his stock, is the quickest way of becoming familiar with the types of coil in general use.

In order that the coil may be used for medical purposes, there must be some method of regulating its strength. The following methods are in actual use in medical coils:

1. By the use of a sliding core to vary the strength of the magnetic field.

This method requires the use of an auxiliary electromagnet to operate the interrupter, and that arrangement gives irregular currents of low frequency, particularly when the weight of the hammer is great or when it vibrates in a vertical direction. The shocks from coils so fitted are unpleasant, and they are bad instruments for electrical testing, and for most kinds of electrical treatment.

2. By the use of a movable secondary coil (sledge coil), which can be brought into stronger or weaker parts of the magnetic field of the instrument.

This method of regulation is a good one; it gives a wide range of current strength, but is only suitable for regulating the secondary current. With a good secondary coil there is little or no advantage to be gained from using the primary for testing or treatment.

3. By the use of a metal tube to slide over the iron core and shield the coils from its magnetic action through the effect of the tube as a closed conducting circuit. The method hardly gives a sufficiently wide range of current strength. The shielding effect is best seen with a tube of thick copper.

4. By using a resistance to vary the current in the exciting circuit.

5. By a switch for bringing into action a greater or lesser number of turns of the secondary winding.

This method gives regulation in steps, and may not allow of sufficiently fine adjustment.

6. By the use of a variable resistance in the secondary circuit.

Methods 1, 3, and 4 regulate both the primary and secondary circuits, the others regulate the secondary circuit only.

In choosing a coil it is important to see that the interrupter works smoothly, for many coils are defective in this important respect, and give irregular shocks, which are very unpleasant. Before buying, it is a good plan to set the coil in action, and to test it upon the hand or cheek. A good interrupter gives out a smooth musical note. It should not make a clattering sound. It is a convenience to choose a coil which is driven by a dry cell, as these cells give the least trouble.

The character of the discharges of an induction coil are modified by the number of turns of wire in the secondary windings. A coil of few turns (two or three hundred) has a lower electromotive force and a lower resistance than a coil of many turns (two or three thousand), and besides its resistance there is another factor which increases with the number of turns, and is known as its self-induction ; this retards the rate of rise and fall of current in the coil, and diminishes the magnitude of the current which can be taken from it. Thus a coil of many windings has a high electromotive force so long as very small currents are taken from it, but this falls rapidly when the resistance of the external circuit is low. A short coil has a lower electromotive force, but is capable of giving a proportionately larger current with less fall in its electromotive force. For treatment with moistened skin and wet electrodes a long coil is not needed, but for the stimulation of the superficial cutaneous nerve endings with a dry skin and a wire brush—a method sometimes adopted—a long coil is needed, as the dry skin has a very high resistance, and requires a high electromotive force to drive through it even the small current which can be borne in this mode of treatment. Some medical coils are therefore provided with two interchangeable secondary coils ; but the same advantage can be had from a single coil if its windings are tapped so that either the whole or a part can be used at will.

Fig. 31 shows a simple form of portable medical coil which answers all requirements, and has its secondary coil subdivided

so that one-third of the windings forms a short coil secondary, while the effects of a long coil can be had by using the whole of the windings.

Duchenne long ago maintained that the physiological effects from long windings (secondary) were not identical with those from short (primary). At that time electrical science could offer no explanation of this. It was suggested that the difference was a matter of electromotive force, which is greater with a long secondary. This did not satisfy Duchenne, because the differ-

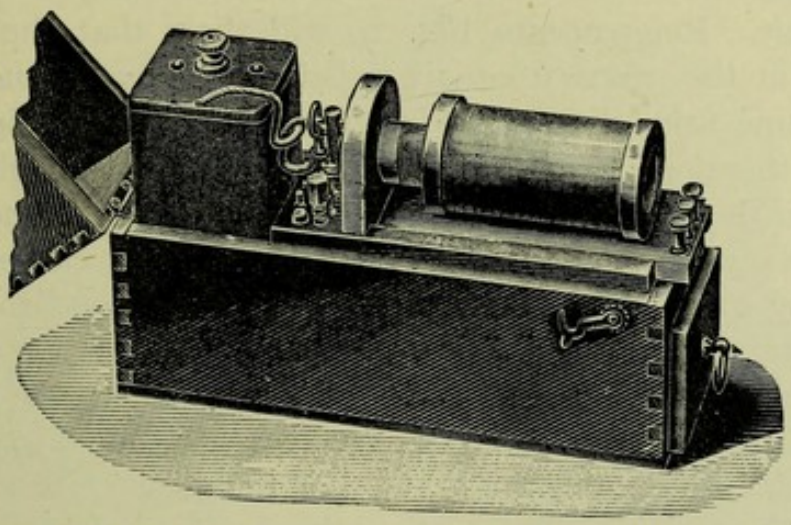

FIG. 31.—PORTABLE SLEDGE COIL, WITH SUBDIVIDED SECONDARY WINDING.

ences observed by him were independent of the mere strength of the electromotive force or current. Differences in these points may be adjusted, and were adjusted by him, but the innate differences in quality remained in spite of adjustments. The essence of Duchenne's contention was this, that the ratio of motor to sensory effect was not identical in the two types of coil, and that with long coils (secondary) the sensory effects were strong at weak degrees of motor effect, while with short coils (primary) the opposite was the case.

60. **Measurement of Induction-coil Currents.**—Some of the methods of comparison or measurement which have been proposed for use with medical coils deserve to be mentioned. The oldest is that proposed by Du Bois Reymond, and still in general use in physiological laboratories. In this the secondary wire is wound on a separate bobbin (sledge coil), which can be moved to and fro along guides so as to bring it nearer to, or further from, the primary coil. A millimetre scale on one of the guides, or on

the base board of the apparatus, serves to mark the relative positions of the two coils, and the measurements are made in millimetres of distance. The method is of some use when applied to identically wound coils which are identically excited, though variations in the action of the hammer are not taken into consideration, whereas these may be of considerable importance.

The measurement of the electromotive force and current of the "primary" circuit is complicated by the influence of the battery which drives the coil, and which exerts its own proper action upon any measuring instrument which may be put into the circuit. Reference to Fig. 16 will show that the current induced in the primary circuit is led off by two branch wires which come from the two ends of the primary windings. The patient, therefore, is in shunt to the exciting circuit when connected to the terminals at P, and a galvanometer connected up in his place would carry some of the battery current. The secondary coil, however, is an independent coil, and the effects of induction in it can be measured, though not by an ordinary galvanometer. With such an instrument the alternate impulses from the coil tend to deflect the needle first in one direction and then in the other, with the result that the needle either remains quite still or else oscillates about its position of rest. If the magnetic needle be replaced by a small bundle of fine soft iron wires, these have no magnetic polarity, and will be attracted by the coils of the instrument quite independently of the changes of direction of the current in the coils, and by means of such a soft iron bundle steady deflections are obtained with the currents of a secondary coil.

Mr. Giltay of Delft, Holland, has made an instrument* on this principle for use with medical coils. In it a bundle of soft iron wires are suspended between a pair of coils in a position at an angle of 45 degrees with their axis. When a current traverses the coils, the core tends to set itself in the axis of the coils, and its movements are made visible by means of a scale and pointer.

Dr. S. Sloan of Glasgow has designed a "Faradimeter" for the measurement of the currents of medical induction coils. His instrument is superior to that of Giltay in several respects, particularly in simplicity of construction and in portability. The moving part in this case is not a bundle of soft iron wires, but is a suspended and freely-moving fine wire coil. An account

* *Ann. der Physik und Chemie*, Bd. 50, Leipzig, 1893 (figure).

of this instrument will be found in *The Journal of Physical Therapeutics*, vol. iii. (April, 1902).

The electromotive force of an induction coil can be best measured by an instrument invented by Lord Kelvin, and known as an electrostatic voltmeter. It is based upon the mutual attraction of two bodies oppositely electrified, and has the advantage of using no current, and therefore it measures the electromotive force of the coil on open circuit, subject to

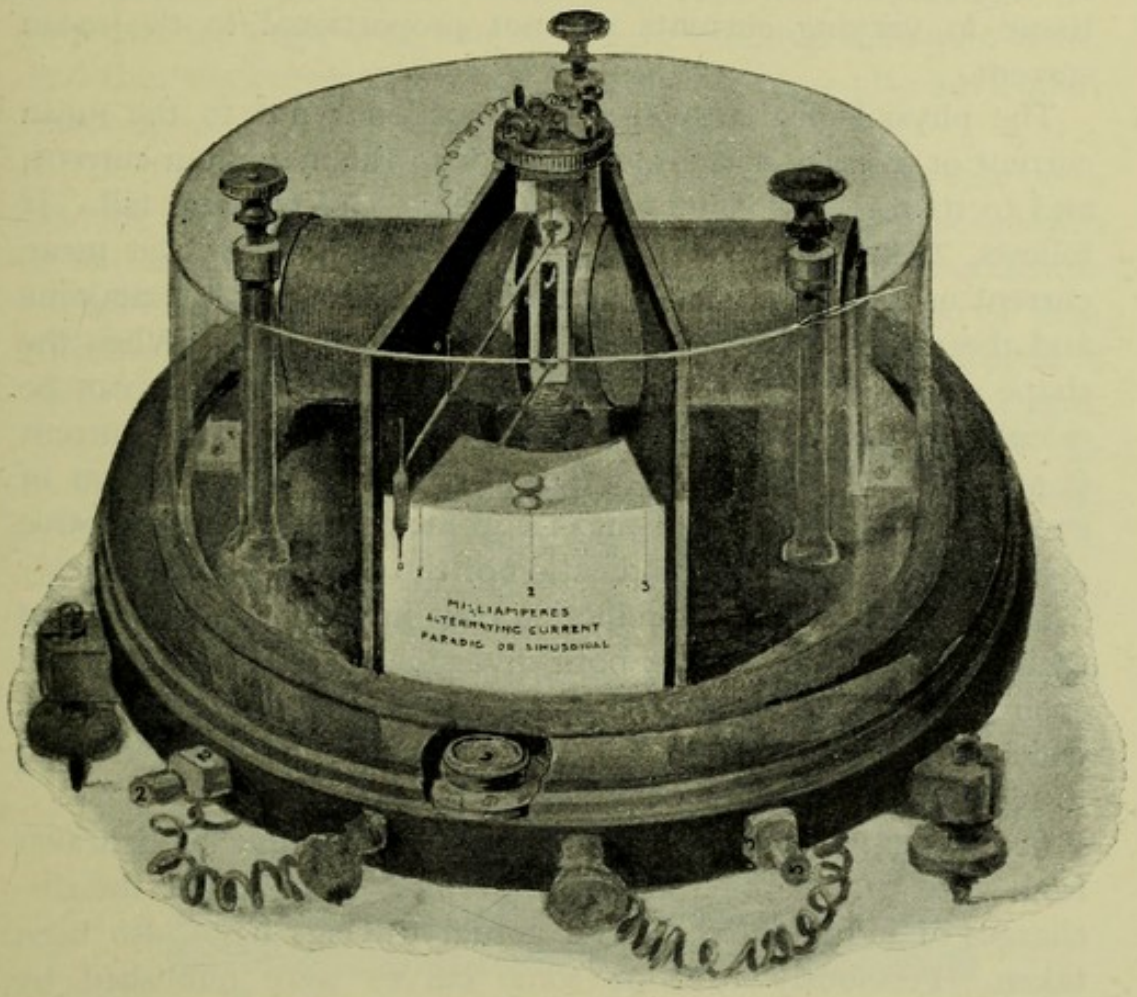

FIG. 32.—THE SLOAN FARADIMETER.

corrections for the capacity of the voltmeter. When the circuit of an induction coil is closed the voltage at its terminals falls away rapidly, particularly if it be closed through a low resistance.

A particular secondary coil was tested by means of an electrostatic voltmeter, and the potential difference at its terminals on open circuit was nearly ninety volts, but when the circuit was closed through a resistance of 1,000 ohms, in shunt to the voltmeter, the potential difference registered was only ten volts.

This observation shows the importance of measuring the electromotive force of a medical coil under conditions resembling those under which it is to be used, and teaches us that some coils with long windings may appear to have a much higher electromotive force than they actually possess under conditions of use.

In all these methods of measuring induction-coil currents we find ourselves face to face with a physiological difficulty, which is that the measuring instruments indicate the mean current of the apparatus, but the motor and sensory responses of living tissue to varying currents are not proportional to the mean current.

The physiological response is proportional, not to the mean current or average current, but rather to the maximum current, and to its rate of change or its suddenness of rise and fall. It follows, therefore, that it is not enough to know the mean current or mean electromotive force of a coil unless the maxima and the rate of change can be deduced from them. When the shape of the curve of a current is known the maxima can be calculated from the observed magnitudes of the mean current (§ 52), but if the shape of the current curve is unknown or irregular, then readings of mean current or mean electromotive force are not a sufficient indication of the physiological effect.

In the case of medical induction coils in general the shapes of their curves of current are both diversified and inconstant, and even for any single coil the determinations of its characteristics which might be made on one day could not be depended upon to recur unaltered on the next.

61. **Current Curves of Coils.**—Many curves have been drawn from time to time on theoretical grounds to represent the discharges of induction coils, and actual tracings have also been taken. Previously to 1894 some curves were published by Dr. Kellogg,* and his method of doing so by means of an instrument devised by himself is fully described in his paper, which is a valuable contribution to our knowledge of the medical coil.

We have already seen that the secondary-coil current is alternating in direction with its two semiphases unequal. The greater the number of the secondary windings the longer will be the total duration of each discharge. At a slow speed of the interrupter the make and the break discharges are distinct from

* "The International System of Electrotherapeutics," edited by Dr. Bigelow (F. A. Davis and Co., Philadelphia, 1894).

one another with intervals between them. At a more rapid speed the discharges will follow each other without any period of no current between them, and with still more rapid interruptions the make and the break waves will interfere with each other.

The accompanying tracings of the secondary discharges of induction coils throw light upon the differences observed by Duchenne between the physiological effects of short primary and long secondary coils. They show that the durations of the impulses are longer with long secondary windings than with short, and that the presence or absence of the iron core also has a great effect upon the length of the current waves.

The tracings are taken with a Duddell's oscillograph on a moving photographic plate. The speed of the plate is uniform in all the tracings represented, and this permits of measurements of the duration of the different current waves, and also of their direct comparison, so far as times are concerned. The length of each of the succeeding tracings represents about $\frac{1}{25}$ second. They run from left to right. In Fig. 33 the curve of the exciting current (E) in the primary coil is shown above that of the secondary (S). In Figs. 34, 35, and 36 it is below. In all the curves of the secondary coil the wave at break is above the base line, and the wave at make is below it.

Fig. 33 shows that the vibrating hammer interrupter is apt to be a defective device, and does not always produce clean,

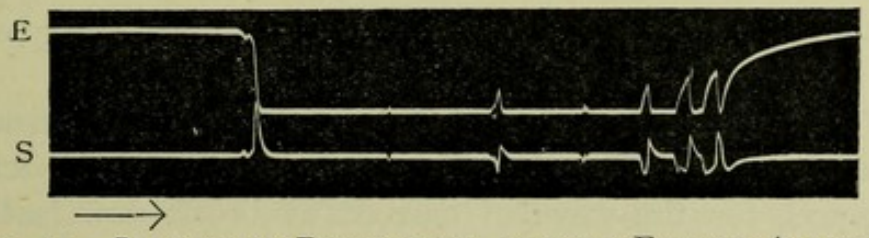

FIG. 33.—IRREGULAR DISCHARGES, DUE TO FAULTY ACTION OF INTERRUPTER.

S, secondary curve; E, exciting current.

sharp makes and breaks. In the tracing six inadequate attempts at contact can be counted before the proper establishment of the steady flow at make, while at the break of circuit there are also two irregularities.

As each of these partial contacts is reflected in the curve of the secondary circuit, it is thus seen that the secondary current of a coil so fitted is of great complexity, and one finds in practice

that it is highly disagreeable. The rate of this type of interrupter is slow. In the figure each interval lasts 0·025 second, and each impulse about 0·016 or more; the whole cycle, therefore, occupies 0·04 second, a frequency of 25 per second, which is not very suitable for medical applications.

Induction coils with auxiliary electromagnets for operating the hammer give these irregular currents of low frequency.

Fig. 34 shows the character of the current waves of a coil with a long secondary when the iron core is removed. The lower curve shows the growth, the period of steady flow, and the abrupt rupture of the exciting circuit, while the upper shows the currents induced in the secondary coil. It is easy to see which one of the waves corresponds in time to the make and which to the break of the exciting circuit; the former starts less abruptly

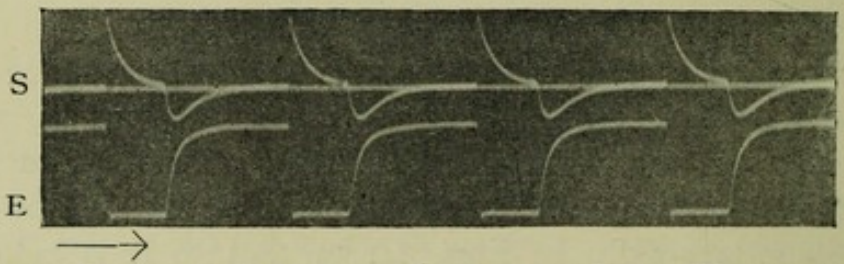

FIG. 34.—CURRENT CURVES OF COIL WITH LONG WINDINGS, BUT WITHOUT CORE (MECHANICAL INTERRUPTER).

S, secondary curve; E, exciting current.

from the zero line, and is a lower wave than the latter. Their durations as measured are about 0 0025 second, the frequency of the interruptions in this particular instance being one of 80 per second.

In Fig. 35 everything is as before, except that the iron core has been inserted. The change in the contours of the tracings is profound, for the wave of current at break now lasts half as long again (or about 0·0037 second), while the current at make is prolonged to more than 0 01 second—that is to say, it has a duration nearly three times as long as was the case when no iron core was present.

It is also instructive to compare the lower curve which represents the exciting current. Its rise is slow, so slow that it has not reached the steady state at the moment of rupture, although the rate of interruption is a slow one.

Another interesting point is the effect of alterations in the speed of the interrupter. As would naturally be expected from

the duration of the waves, a speed can be reached at which the waves at make and at break begin to tread upon each other's heels, so to speak, so that before the make wave is over it is

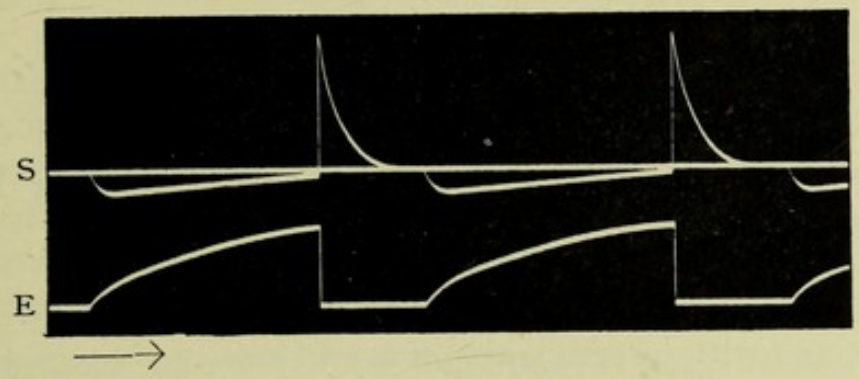

FIG. 35.—CURRENT CURVES OF COIL WITH LONG WINDINGS, AND WITH IRON CORE.

S, secondary curve; E, exciting current.

suddenly reversed by the wave at break, and *vice versâ*. Fig. 36, from the same coil, shows this point clearly.

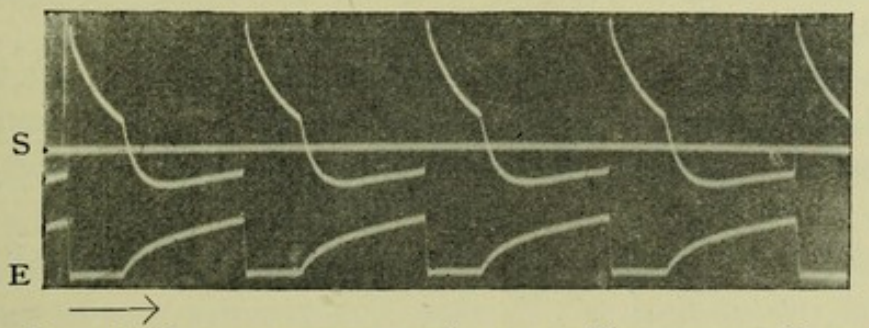

FIG. 36.—INTERFERENCE OF CURRENT WAVES WITH RAPID INTERRUPTIONS.

S, secondary curve; E, exciting current.

The extent of the interference of the two waves of current depends upon the character of the contact-breaker, and varies in different coils. The more rigid the spring the more likely it is that the rebound or break will follow too quickly upon the make. The shocks of an induction coil can often be very considerably altered in character by a little adjustment of the contact-screw, because changes in its position may alter the play of the spring, and so make a difference in the way in which it rebounds after contact. This change in the action of the interrupter can often be recognised by an alteration in the note or sound which it gives out. Again, the interference of the current waves will be more readily produced when these are long than when they are of short duration. Thus a coil with long windings and a heavy core must

be worked at a lower rate of interruption than is permissible with a short coil, if it is wished to keep the waves of current separate.

The length of the primary winding is also a factor, for the self-induction of a long primary will exercise its own retarding effect upon the growth and decay of current.

Thus for painless muscular stimulation the best construction would be one with short windings both in primary and secondary, with no iron in the core, and with a mechanical interrupter. The best frequency of impulse for muscular stimulation has been determined by Leduc as that of 100 interruptions per second, with durations for the individual waves of one-thousandth of a second, and with intervals nine times as long.

As induction coils must have an iron core if they are to be operated by the ordinary vibrating spring contact-breaker, we are at once confronted by a constructional difficulty, and must inquire afresh as to whether it is possible to employ an iron core and still to obtain waves of short duration. The answer to this is in the affirmative if pains be taken in the general design of the instrument, and the interrupter is light and springy.

Figs. 37 and 38 show the curves of secondary current in the case of a coil having a slender core of about twenty-four iron wires, which is sufficient for the automatic operation of the interrupter.

From these we see that the waves of a well-constructed

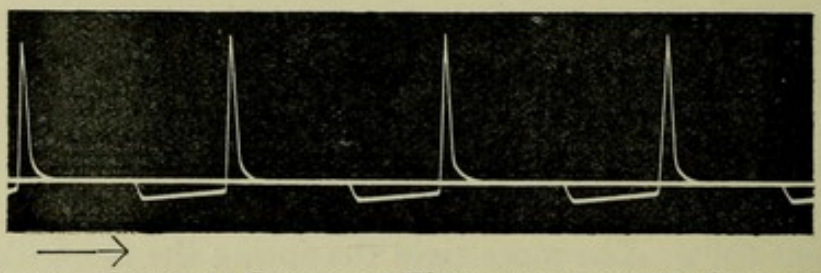

FIG. 37.—CURRENT CURVE OF WELL-CONSTRUCTED COIL, USING ONE-THIRD OF THE SECONDARY WINDING.

coil may be very short, and that the good points of such a coil are not seriously impaired by the presence of a small amount of iron in the core. The curve shown in Fig. 37 possesses just the characteristics advocated by Leduc, except that the frequency is not quite that of 100 per second. These tracings are taken with the coil represented by Fig. 31, a form of coil designed empirically by myself some years ago, and constructed by Mr. Schall. It is interesting to note that this coil has found

much favour with the medical profession, and is made and sold in considerable numbers, doubtless by reason of the agreeable character of its discharges.

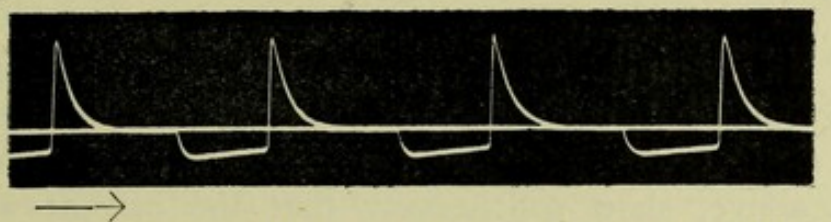

FIG. 38.—CURRENT CURVE OF SAME COIL, USING THE WHOLE SECONDARY COIL.

62. **Sensory Effects of Coil Currents.**—It may be asked why alternating current from a dynamo is not used for purposes of testing in order to escape the uncertainties of the induction coil, and the answer to this question is one of considerable interest. So far as measurement goes, the use of the sinusoidal current of the electric light mains for purposes of testing would be most convenient, because, as we have seen, the shape of its current curve is uniform and regular (§ 52), but unfortunately it produces, when used in the ordinary way in medical applications, a stinging effect upon the sensory nerves which interferes seriously with its use. This particular point helps o provide an explanation of the phenomenon observed by Duchenne that the current of the secondary coil has a greater effect upon sensory nerves than the current of the primary coil, and of the well-known fact that secondary coils of different construction produce very different degrees of painful effect.

The duration of each discharge of an alternating current having the not uncommon periodicity of 100 is one two-hundredth (0·005) of a second, and that of the secondary circuit of a coil may have a somewhat similar duration.

In 1903 Dr. Henry Head observed that a great change was produced in the sensory effect of a certain type of coil by withdrawing the iron core. The current when the core was inserted was of a disagreeable character, but was free from this character when the core was withdrawn, and this difference in quality was found to be quite independent of the actual strength of the current, as estimated from the degree of muscular contraction set up.

In discussing the matter with him I suggested that the explanation might be found in the greater duration of the

current waves when the iron core was inserted, and soon afterwards Dr. Head was able to obtain some oscillograph tracings of the currents of his coil which confirmed that suggestion by showing that the insertion of the core which increased the painfulness of the current also increased the duration of the current waves. It was this interesting discovery which has led to the investigation of the current waves of various coils by the oscillograph method. The tracings obtained, some of which are figured above, show conclusively that the current waves of medical coils in common use may range in duration from one two-hundredth to one thousandth of a second (0·005 to 0·001) for the currents at break. The impulses at the "make" may be even longer, but as they are usually of considerably smaller magnitude, they are probably of minor importance.

The conditions under which long waves are produced are the conditions associated with a high degree of self-induction, and this is greatest in coils with long lengths of wire in the primary and secondary windings, and in coils with much iron in the cores. When the interrupter is operated by an auxiliary electro-magnet in the circuit the self-induction of the whole circuit is notably increased, and shows itself in the increased length of the waves, the wave of current at "make" in the secondary circuit being especially long under these circumstances.

The effect upon the contraction of striped muscle seems to be alike for long and for short waves within the limits existing in the discharges of medical coils. The effect on sensation, on the other hand, is very greatly influenced by the length of the waves. Thus waves with a duration of 0·005 second (one two-hundredth of a second) possess the stinging painful quality in a high degree, and this decreases as the waves grow shorter, and is lost for wave-lengths whose duration is less than one four-hundredth (0·0025 second) of a second.

Dr. Head has used this difference of quality between differently constructed coils to analyze the whole system of sensory conduction in a masterly paper, which will be more fully touched upon in a subsequent chapter. It will now be easy to understand why the sinusoidal current of the electric lighting mains is too painful in its effect to be suitable for use in electrical testing as a substitute for coil currents.

63. **Mechanical Interrupters.**—When the question of the use of coil currents in diagnosis is examined we find that there is

no apparent reason why interrupted currents from other sources should not be used in their stead. Dr. S. Leduc (Nantes) has recently called attention afresh to this matter, and by using a continuous current source and a mechanical interrupter he has shown that all the effects upon muscle which are generally considered to be peculiar to the induction current or "faradism," as it is commonly called by medical men, can be produced by means of a battery current mechanically interrupted.

Leduc's apparatus consists of a revolving commutator driven by a small electric motor. By an ingenious arrangement of collecting-brushes the circuit is closed for a certain fractional part only of each revolution of the commutator. With this apparatus the number of impulses per second can be varied by varying the speed of revolution of the motor, and their duration—that is to say, the period during which the circuit is closed in each revolution—can be regulated by moving the position of one of the brushes. Working with this apparatus Leduc has found that for the rate of one hundred intermittences per second the best physiological effect corresponds to durations of time of current flow of one-thousandth of a second, with nine-thousandths of interval, and any increase or decrease from these proportions of time of current flow requires an increase in the electromotive force needed to produce a minimal muscular contraction. With this apparatus the rise and fall of current is more brusque or sudden than with alternating currents from a dynamo or from an induction coil.

Its advantages are as follows: The current used in testing can be measured directly in milliampères; the volts applied can be measured equally well if desired, the frequency of the interruptions can be regulated and measured in a moment by the addition of a speed-counter, and, finally, the painful effect upon the sensory nerves of the patient can be reduced by the device of using impulses of very short duration. This instrument is bound to supersede the induction coil altogether when exact work and measurement of results are wanted, although, no doubt, the coil will continue to hold its ground for a long time to come as a means of producing simple excitation of nerves and muscles.

Leduc, in describing his apparatus,* writes as follows: "To obtain the interrupted currents I use an interrupter driven by a small motor. An insulated disc is mounted upon the axle,

* *Arch. d'Élect. Médicale*, September 15, 1903, p. 521.

and is fitted with four metallic segments, the opposite segments being connected together to form two pairs (Fig. 39). A pair of brushes is provided, and the circuit is closed from brush to brush through the segments. If the contacts of the brushes with the two segments, composing a pair, occur simultaneously, the current is only interrupted during the short moments during which the brushes are passing over the intervals which separate adjoining segments. One brush is fixed, and the other is movable through an arc of 90 degrees, and by a displacement of the movable brush one can so arrange matters that the circuit only becomes closed when one segment of the pair has already performed a half, three-quarters, or more of its passage under the fixed brush, in which case the current can only get through

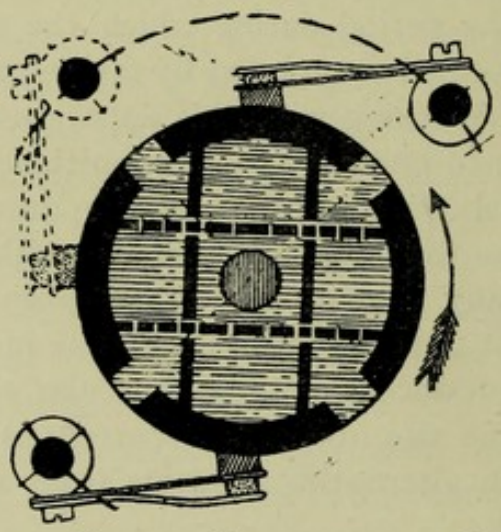

FIG. 39.—PLAN OF COMMUTATOR OF LEDUC.
The dotted lines show the range of movement of the upper brush-holder.

during one-half, one-quarter, or less of the whole period. The speed of the motor is regulated by a rheostat, and this determines the number of interruptions in a given time. The speed of rotation can be measured directly by a speed-counter on the axle. A milliampèremeter in the circuit measures the current, but for correct values it is necessary to compare the readings indicated when the motor is in movement with those indicated when it is at rest. The latter give the true values, and the former can be used as a measure of the duration of the time of passage of the current during each period. If the word 'period' is taken to mean the time between one interruption and the next, the current can pass and be 'on' during one-half, or one-fifth, or one-hundredth of the period, and be interrupted and 'off'

during the remainder of the period. Thus if the current passes during one-tenth of a period and is off for the remaining nine-tenths the current registered by the milliampèremeter when the commutator is rotating will be the tenth of the true current. By thus comparing the currents indicated with the commutator at rest and in motion one can estimate the duration of time during which the current is flowing."

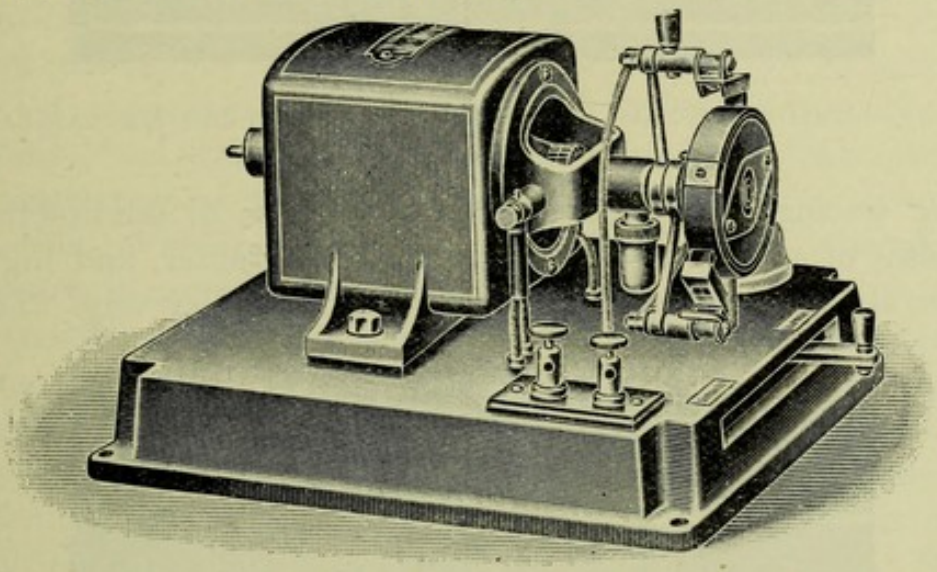

FIG. 40.—LEDUC'S MECHANICAL INTERRUPTER.

Fig. 40 shows a motor fitted with a commutator like that of Fig. 39 and a hinged brush-holder for varying the duration of

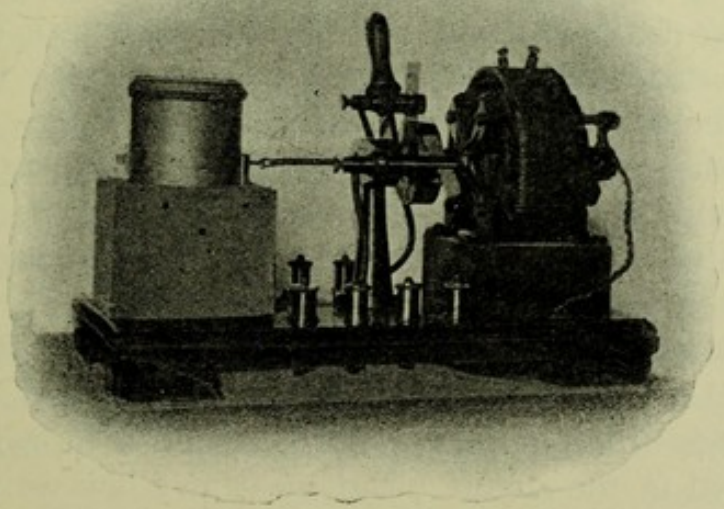

FIG. 41. — MOTOR-DRIVEN INTERRUPTER WITH SPEED-COUNTER AND ADJUSTABLE BRUSH-HOLDER.

the individual contacts, and Fig. 41 shows another similar instrument, which also has a speed-counter, which is a very

necessary addition for experimental work. Dr. Reginald Morton has constructed an instrument which gives interruptions and reversals, and Mr. Schall makes an apparatus with which unidirectional or alternate impulses can be employed at will.

FIG. 42.—UNIDIRECTIONAL CURRENT WAVES PRODUCED MECHANICALLY.

The tracing in Fig. 42 is that of a series of unidirectional impulses of current from a mechanical interrupter, and Fig. 43 shows alternating impulses produced in a similar way. These

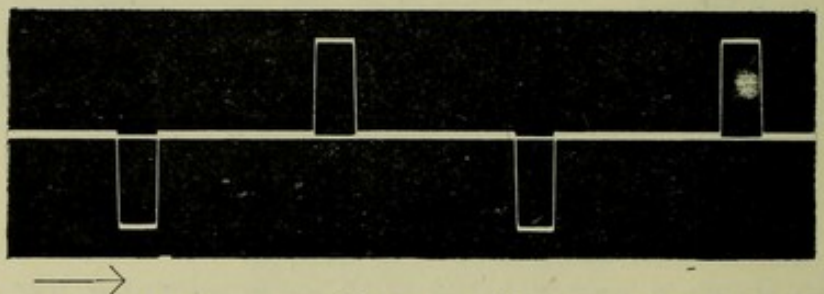

FIG. 43.—ALTERNATING CURRENT WAVES PRODUCED BY A MECHANICAL INTERRUPTER.

figures are from actual tracings taken with the oscillograph. In both the ratio of length of impulse to length of interval is to be noted, and it is to be remembered that by moving the brush-holder the impulses can be made longer or shorter at the expense of the interval without increasing their frequency. The frequency is varied by changing the speed of rotation of the apparatus. In these figures, too, the whole tracing represents a time of one twenty-fifth of a second.

64. **Regulation of Current—Resistances.**—When the current is regulated as described in § 55 it will be seen that, neglecting the resistance of the battery, the electromotive force is the only thing altered in the circuit. But by Ohm's law we know that the current is numerically equal to the electromotive force divided by the resistance of the circuit, so that it might be regulated by introducing or removing resistances, the electromotive force being kept constant. In some cases it is more convenient

to regulate by this method, as, for example, in regulating the current from the electric light mains, in which the electromotive force is maintained at a constant figure. An adjustable resistance for varying the current in a circuit is sometimes called a "rheostat." In general, with batteries, when the total resistance of a circuit is large, it is more convenient to alter the electromotive force than the resistance in the circuit. Thus, suppose a circuit has a total resistance of 3,000 ohms, and is acted on by twelve cells of 1·5 volts each, there will be a current of six milliampères; if now it is required to double the current, it is easily done by adding twelve more cells, taking for granted that their internal resistance may be neglected, but if it were desired to make the alteration by reducing the resistance of the circuit it would be necessary, in order to double the current, to take out a resistance of 1,500 ohms. When it is desired to increase current by taking out resistances it is of course requisite that the resistances to be removed must have been connected up in the circuit before the commencement of the operation. If the total resistance is small this can be done, and in such cases the current is most easily governed by variable resistances in the circuit. Thus, suppose a circuit made up of a cautery burner whose resistance with its leads amounts to 0·01 ohm, and an accumulator whose electromotive force is two volts and internal resistance 0·002 ohm, the current would be well governed by having a variable resistance of half an ohm in the circuit. When the current was turned on with full resistance it would amount to about 3·9 ampères, and by reducing the variable resistance to 0·088 ohm a current of 20 ampères would be given, which would probably suffice to heat the burner.

It must be borne in mind that a resistance, suitable for regulating small currents, may be burnt and destroyed if large currents are allowed to traverse it, also that a resistance of one or two ohms may be ample for regulating a lamp or cautery, but will exercise no appreciable regulating effect upon a circuit of high resistance. In general a rheostat should have a resistance approximately equal to that of the circuit which it is to control.

In medical treatment it is more important to have a resistance which can be smoothly adjusted while the current is passing than one which is graduated exactly in ohms.

A useful form of rheostat is shown in Fig. 44, where a movable

arm is made to touch successively upon a series of metal studs which are connected behind to a resistance whose value is shown by figures marked opposite the studs.

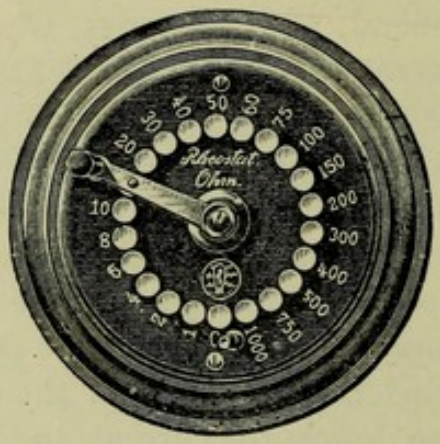

FIG. 44.—ADJUSTABLE RESISTANCE FOR MEDICAL USE.

A form of resistance coil that will frequently be found useful is one which is known as the "wire rheostat." It is very convenient in cases such as the example given above, in which there is a small external resistance only in the circuit, and a large current is to be regulated. It usually consists of a coil of moderately thick uncovered German silver wire. The current is led in at one end of the helix, and leaves it by a metal

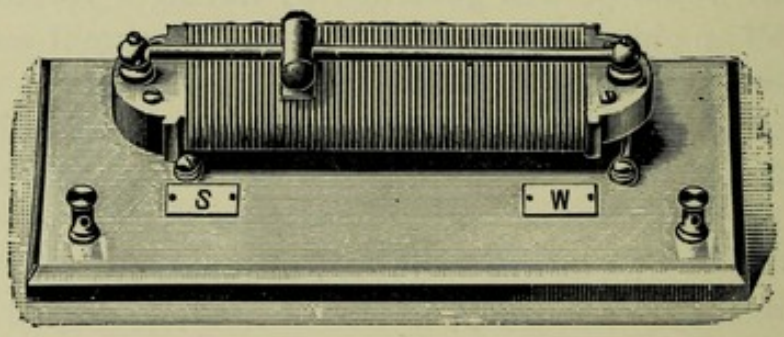

FIG. 45.—WIRE RESISTANCE WITH TRAVELLER.
S, strong; W, weak.

traveller sliding on a metallic arm joined to the other end of the coil. The resistance interposed is easily seen to be proportional to the number of turns of the wire between the end attached to the terminal and the sliding piece. The form of this resistance is favourable to cooling, as the wire is freely exposed to the air. It is especially useful for regulating the current in cautery or lamp instruments (Fig. 45).

A very useful form of adjustable rheostat for high resistances and small currents is a sliding graphite resistance (Figs. 46 and 47). It consists of two parallel pencils of graphite, with a metal

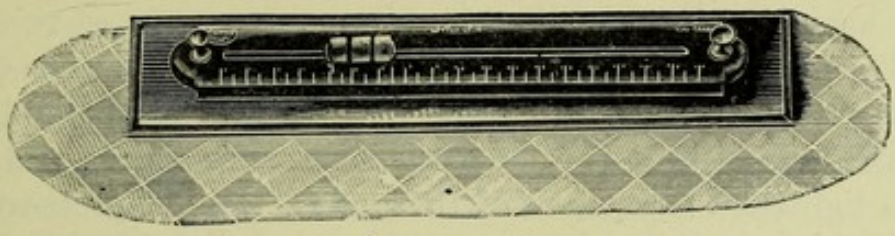

FIG. 46.—GRAPHITE RHEOSTAT.

bridge to slide between them in contact with both. As the position of the slide is altered a greater or less length of the badly-conducting graphite is brought into the circuit, and the resistance

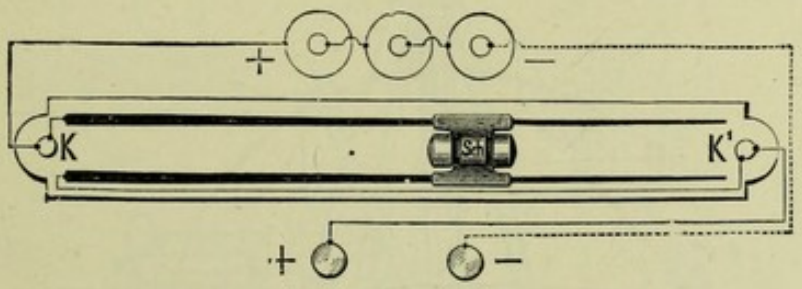

FIG. 47.—PLAN OF GRAPHITE RHEOSTAT.

of the circuit is varied thereby. Graphite rheostats are also made up in other patterns.

Another adjustable resistance apparatus made up in many

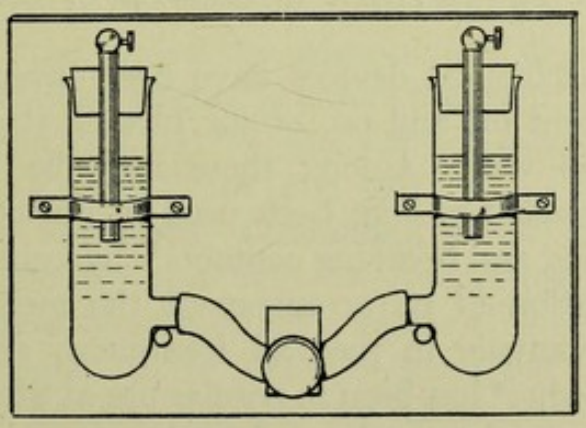

FIG. 48.—LIQUID RESISTANCE OF GUILLOZ.

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forms is the "liquid rheostat." It consists of a glass vessel filled with water or some saline solution, through which the current must pass to reach a conductor which is immersed in it.

The resistance offered by the liquid varies with the length of liquid to be traversed and the nature of the solution, and a wire more or less deeply immersed affords a ready means of varying the resistance in the circuit.

An ingenious form of liquid resistance is made of two glass vessels connected by an indiarubber tube (Fig. 48). The vessels and the tube are fixed to a stand and filled with saline solution. The indiarubber tube is provided with a screw clamp, and when this is tightened the lumen of the tube is gradually obstructed, and in this way the resistance of this part of the circuit can be increased progressively until it becomes practically infinite.

65. **Rhythmic Interrupters.**—In medical treatment it is sometimes useful to interrupt or to vary the current rhythmically,

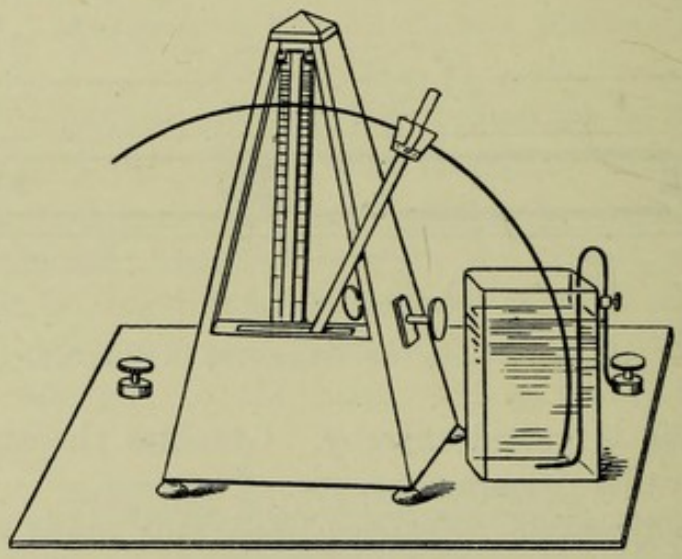


FIG. 49.—RHYTHMIC INTERRUPTER OF LEDUC.

and several mechanical devices have been invented for slowly turning a current off and on, or for turning it off and on and reversing it as well. Among these may be mentioned the metronome, which has long been used in physiological laboratories for making and breaking contacts in circuits at a slow rate. By a modification of its arrangement the metronome can be used with advantage in medical treatment, and the method proposed by Leduc* has been in regular use at St. Bartholomew's Hospital for some time with good results.

The metronome (Fig. 49) has a fine aluminium wire attached to its moving arm, and as this swings to and fro the wire gradually dips down into a vessel of water, and rises out of it again. At

* *Arch. d'Élect. Médicale*, 1900, p. 300.

the bottom of the vessel is a conductor to which the current passes. As the moving aluminium wire approaches the bottom of the vessel the resistance of the circuit gradually falls and the current rises to a maximum, decreasing again as the extremity of the aluminium wire recedes during its upward movement. The fixed conductor is insulated except at its extreme end.

Bergonié has also devised a convenient machine for producing the same result. It consists of a vertically-placed disc of ebonite moved by clockwork and rotating with its lower third immersed in a trough of water. On the edge of the disc is a lozenge-shaped piece of platinum foil which is connected to one pole of the circuit; the other pole is inside the trough of water

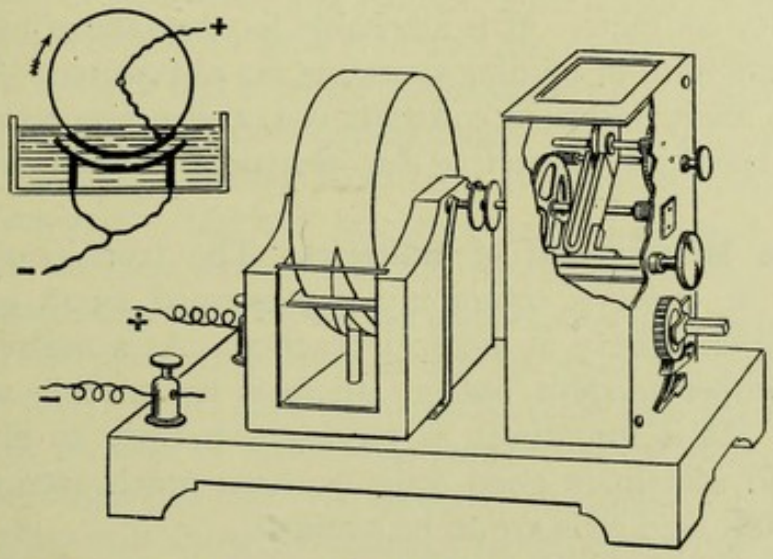


FIG. 50.—RHYTHMIC INTERRUPTER OF BERGONIÉ.

in a position close under the edge of the disc. As the disc revolves the platinum gradually enters the water and approaches the other conductor, and as gradually recedes from it, and emerges from the water again (Fig. 50).

66. **Accessory Apparatus—Conducting Wires.**—The conductors or leads by which the current is conveyed from the battery to the patient should be of stranded flexible copper wire insulated with cotton or silk. It is useful to have the two conductors covered in two different colours, say red and green, to make it more easy to distinguish them in tracing their attachments to the battery or to the electrodes. A convenient length is four feet and a half or five feet. Suitable cords with ends to fit the battery terminals are sold by the instrument-makers.

It is important to know that the wire core of these covered

cords may become broken inside the covering, and give trouble if not discovered, the commonest breaking-point being near the ends. Faulty connections are among the regular accidents tending to throw electrical apparatus apparently out of gear, and although it is not hard to detect the fault by careful examination, yet only too often much difficulty is found, and in consequence the battery is condemned, or the services of the instrument-maker are called in. It need not be said that this is the wrong way of doing things, for everyone using a battery should make himself familiar with the proper management of it, in order to avoid the expense and annoyance of frequent recourse to the instrument-maker.

As a matter of fact, with moderate care no difficulty need occur from faulty contacts. It is advisable for the sake of neatness to use but one form of binding-screw, as far as possible. There are of course many forms in constant use, and a few minutes may be well spent in inspecting an electrical instrument-maker's stock.

67. **The Management of Batteries.**—The trouble of keeping batteries in order is commonly put forward as an excuse for neglecting electricity in medical practice. As a matter of fact, with a proper modern battery there is no trouble worthy of mention. It is important in buying a battery to choose one which will remain in good order without much attention. On this account acid cells are to be avoided.

Care must always be taken to guard against accidental or intentional short circuiting of any battery. Few batteries will stand short circuiting for many minutes; the dry batteries most used in medical practice are particularly sensitive to it. Short circuiting may easily occur if the electrodes are carelessly thrown down after use, and should happen to lie in metallic contact with each other.

It is bad practice to try to test a battery by connecting the terminals by a direct metallic contact except through a coil of high resistance, for the strength of current may be so great as to damage the galvanometer, and it will probably be too large even with one cell for a galvanometer graduated in milliampères to give readings of it. If no resistance coil be at hand the plan of putting the electrodes into a little water in a saucer will usually suffice to reduce the current in the circuit to a quantity which can be measured in milliampères. If the battery be not

fitted with a galvanometer, one must be attached for this mode of testing. It may be connected to the terminals of the battery, in series with the resistance employed. If this has a value of about 1,000 ohms the current is reduced to a magnitude suitable for measurement with the milliampèremeter; the pointer must then be gradually moved round the studs, the galvanometer being watched carefully. If the battery is in proper order it will indicate a regular rise in current step by step for every cell added to the circuit. If the galvanometer needle falls to zero as the pointer is passing from one stud to the next it indicates that the current is broken at that moment, and if a patient were in circuit he would receive an objectionable shock. If the needle falls to zero when the pointer is on a stud it shows that the connection between that stud and the battery is faulty.

When a battery has been dismounted and put together again, especially if it has many complex connections, there is a danger that the positive pole may have been accidentally connected to the binding-screw marked negative and *vice versâ*. This is sometimes the case even when the repairs have been done by an instrument-maker. This is an important point, because confusion of the poles may lead to serious mistakes and even to injury to the patient. All risk can be done away with by the use of some method of testing the polarity of the electrodes. It is easy to improvise one. A piece of wet litmus paper on a piece of glass will show by changes in colour at the electrodes which is the positive and which the negative pole. The ends of the wires from the battery must be rested on the paper for a few moments, electrolysis will take place, and the litmus will be reddened by the acid liberated at the anode or positive pole, and will turn blue at the kathode or negative pole. Other reagents have been proposed; for example, paper impregnated with a solution of phenolphthalein is used as a "pole-finder," and gives a purple red colour at the kathode or negative pole.

For medical men the use of litmus paper is the most simple means of determining the polarity of wires or terminals, because litmus paper is a reagent which they have always at hand.

68. **Electrodes.**—The conductors through which the current is applied to the body are called electrodes. The word electrode has also been used to describe the connections by which the current leaves the battery or enters any instrument, and also the

wire conductors of a circuit, but in medical usage the word electrode is employed to signify the special terminals which are applied to the patient. The special terminals used in medical treatment were formerly called *rheophores*. The variety in nature and shape of the electrodes used in medical practice is great, and it will be useful to describe some of them.

The old-fashioned brass handles and wet sponges should be wholly abandoned, and the proper form of electrode to use is a disc or plate of metal covered over with chamois leather, or some other absorbent material.

Care must be exercised to keep the electrodes clean, and on this account metal is a better material for electrodes than carbon. Uncovered metal must not be applied directly to the skin, as it produces painful sensations, or may even cause sores, by electrolytic action upon the surface of the skin. The sheaths and covers must be often renewed, and as far as possible a separate set should be kept for each patient. Lint, absorbent cotton-wool, and even asbestos cloth and blotting-paper, have been used for covering the electrodes.

In some medical applications both the poles of the battery are

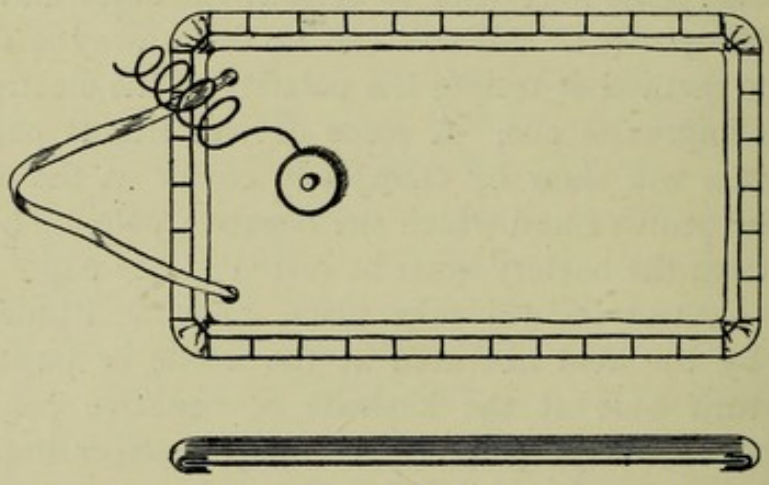


FIG. 51.—PLATE ELECTRODE AND MODE OF COVERING IT.

used equally, and in that case the electrodes at the two poles may be similar, but more often the current is applied to the affected part with one pole, which is then known as the "active electrode," the circuit being completed by the application of the other electrode, the "indifferent electrode," to any convenient part of the body; under these circumstances the active electrode generally has a handle for its proper manipulation, while the indifferent electrode is most conveniently arranged as a padded

metal plate, which can be applied to the surface of the body and left there during the treatment. Zinc plates may be used, but the best metal of all is silver. On the back of the plate a binding-screw is affixed for the attachment of the battery wire, and the other side is covered with the absorbent material, which must be moistened with warm water or salt and water before use. In addition there may be a sheath or pocket with a mackintosh back to contain the electrode, and to serve to protect the patient's clothes from being wetted. Red Turkey twill makes a good material for the front side of the sheath.

A good electrode needs a sufficient layer of absorbent material to cover its surface, and this if folded over the edge of the plate tends to make the electrode thick and clumsy; on the other hand, if the edge of the plate is not protected the skin of the patient may be injured during the course of a long application. To meet this difficulty an edging of jaconet or other thin waterproof fabric should be sewn on round the edge of the plate beneath the rest of the covering. The metal plate is perforated all round the edge with small holes for the purpose, and after the jaconet has been affixed three or four layers of lint cut to the exact size of the electrode are applied to the plate, and kept in position by an outer layer of cambric or linen, which is cut of sufficient size to be brought round to the back and sewn on securely by stitches arranged as seen in Fig. 51. An electrode made in this way can be safely used without any sheath, does not wet the patient's clothing, and is thin enough to allow of easy insertion at the back of the neck without the need of loosening the collar. The most convenient shape for the plate is an oblong measuring about five inches long and two and a half inches broad, with rounded corners. The loop of tape is useful for removing the electrode after use.

When the indifferent electrode is slipped between the clothing and the skin the pressure of the clothes serves to keep it in place, or if the patient is lying down the electrode may be put underneath the shoulders or the hips, or it may be held against the body by the patient himself, or by an assistant. In either case the operator is able to give his whole attention to the other or active electrode. Care must be taken to see that the contact of the indifferent electrode with the skin is well maintained, and that no dry clothing lies between. Sometimes, especially with children, it may be fastened on by a few turns of a bandage, or

by a soft garter or belt of some kind. Electrodes to buckle or clasp upon a limb are figured in the catalogues, and are sometimes useful.

For the active electrode metal discs of several sizes are required, and for large currents large electrodes should be used.

It will generally suffice to have three or four sizes of disc electrode, the smallest of half an inch or one centimetre in

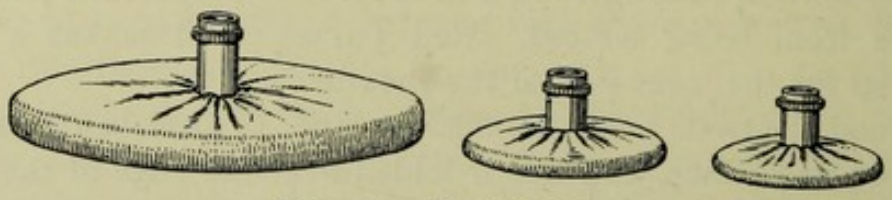


FIG. 52.—ELECTRODES.

diameter, the largest of four inches. A roller electrode is sometimes useful, and occasionally an electrode in the form of a wire brush is used to produce a brisk and painful cutaneous stimulation. Chamois leather is a good covering material for these disc electrodes (Fig. 52).

A very good form of disc electrode, in which the operation

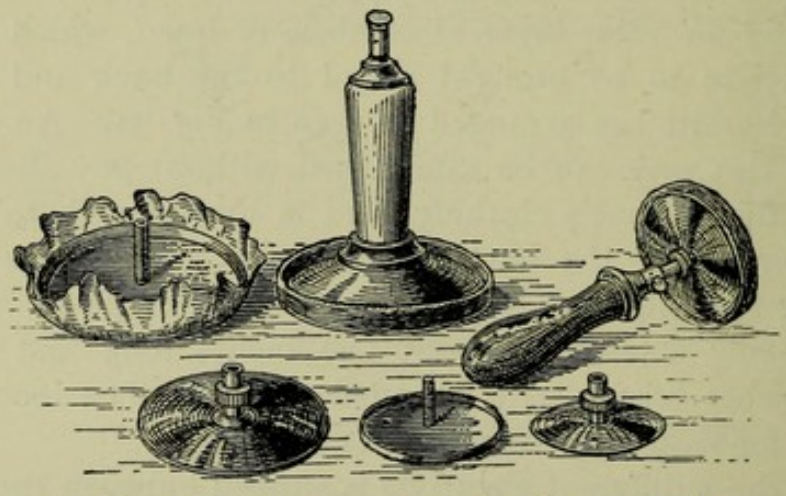


FIG. 53.—DISC ELECTRODES, SHOWING MODE OF AFFIXING THE COVERS.

of renewing the leather covering can be quickly carried out without needle and thread, is shown in Fig. 53. It consists of two cupped discs of metal, which screw together, and so hold the edges of the wash-leather firmly fixed between them.

The more special forms of electrode will be described and figured in the chapters which deal with the particular operations in which they are used.

For testing purposes an electrode handle should be provided with a key for closing the circuit. Electrodes with opening keys are also made, but are less useful.

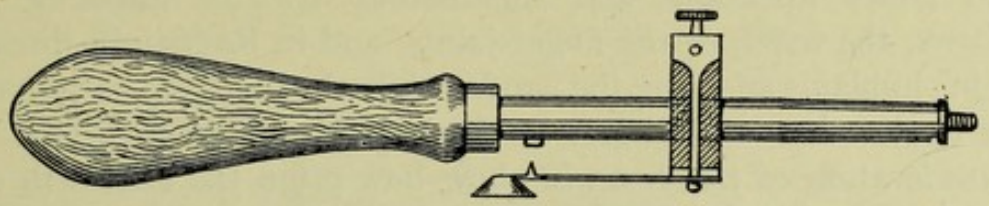


FIG. 54.—ELECTRODE HANDLE FOR TESTING WITH 'CLOSING KEY.'

69. **Baths as Electrodes.**—We have already seen that electrodes with large surfaces of contact are desirable when large currents are to be passed through the body. For this reason vessels containing water or saline solutions are sometimes used as electrodes, and they have the advantage of conveying the current to the surface of the body in a very even manner.

Very large currents can be sent through a patient by the use of baths as electrodes. This use of baths is convenient in applying electricity to the extremities, and it has been further developed into a method of treating the whole of a patient's body at once by immersion in a full-length bath. For these reasons the use of local and general baths for conveying electricity to a patient require describing in some detail. The use of the arm-bath or foot-bath greatly simplifies the process of applying electricity to a patient by doing away with the tedious process of rubbing the electrodes over the affected parts. It is therefore a valuable method of applying electricity, and one which deserves general adoption by the medical profession. The continuous current, the interrupted, or the sinusoidal current, may be given with equal advantage through the medium of baths.

Any non-conducting vessel of suitable size can easily be arranged to serve the purpose. The oblong stoneware troughs or pickling-pans made for kitchen use are exactly suited to take the hands and forearms, and Mr. L. Miller (93, Hatton Garden, E.C.) can supply them with electrodes already fitted.

A good form of electrode is one made of sheet-metal cut out in one piece in the shape of a tennis bat, with the handle part bent into a hook, which serves to hang the electrode from the end of the trough. It is fitted with a binding-screw at the extremity.

The arm-bath is specially suited for cases of paralysis of the

muscles of the forearms and hands, as, for example, in the extensor paralysis of lead-poisoning, and in paralysis from injuries to the nerves of the arm and forearm ; also in rheumatic and gouty affections and rheumatoid arthritis affecting the elbows, the wrist, or the finger-joints, and in Raynaud's disease, or in chilblains affecting the hands, while the foot-bath is valuable for applications to the feet in the last-mentioned disorders. A consideration of this list will show how often the arm-bath can be of service, particularly in general practice or in the electrical department of a hospital.

When an electric bath is so arranged that one electrode only is immersed, and the whole current passes from it to the patient, it has been called a monopolar bath, to distinguish it from the dipolar bath, which consists of a vessel of water in which both electrodes are placed so that the current passes from one to the other through the water. A limb immersed in such a bath receives part only of the current flowing between the electrodes, the remainder being carried by the water and wasted.

The dipolar bath is useful for the treatment of the forearms and hands, but has its chief application in the full-length electric bath to be described below.

When a monopolar bath is used as an electrode the other may consist of an indifferent electrode of large size placed upon some part of the body, or it may have the form of a second bath, and this is generally the best arrangement.

70. **The Four-cell Bath of Dr. Schnee.**—This is a monopolar bath carried to a high degree of elaboration. It consists of a special chair provided with four baths, one for each limb of the patient who sits in the chair (Fig. 55). The baths are fitted with carbon electrodes connected to the source of current, which can be made to traverse the patient's limbs in any required manner. Thus in cases of paraplegia the two foot-baths could be used, in hemiplegia one arm-bath and one foot-bath, and so on. A switchboard forms part of Dr. Schnee's apparatus, and it is fitted with voltmeter and ammeter, with an adjustable resistance for purposes of regulation, and with a small motor generator by means of which sinusoidal or interrupted current can be supplied to the baths. There is also a simple arrangement of switches, so that any of the baths can be made either positive or negative at will.

One of these instruments has been in use at St. Bartholomew's

Hospital for several years, and has proved to be a valuable appliance for the electrical treatment of many kinds of cases. When used with direct current 20 milliampères can be comfort-

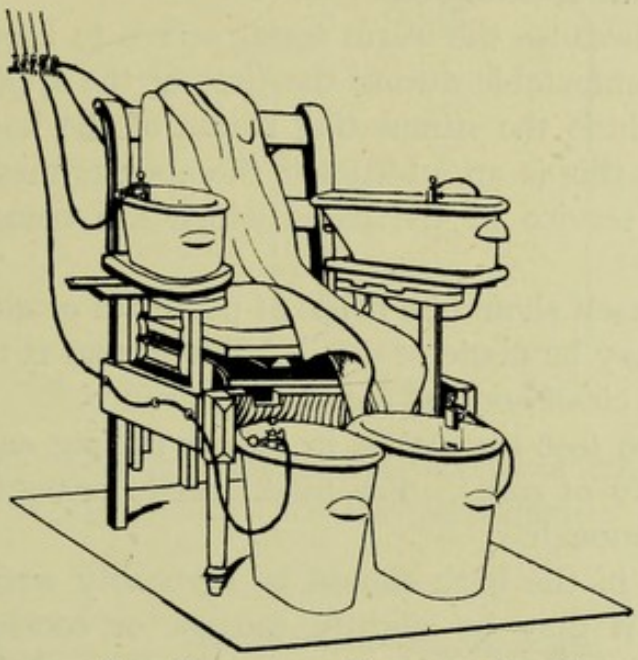


FIG. 55.—THE FOUR-CELL BATH OF DR. SCHNEE.

ably borne from arm to arm, and the electromotive force needed to produce this magnitude of current is about 25 volts.

71. **The Electric Bath.**—The full-length bath, in which the patient is completely immersed, may now be considered. It is used in the treatment of many morbid conditions because it provides a convenient and agreeable way of applying general electrisation to the whole system, a mode of treatment of great value whenever general stimulating and tonic effects are required.

The electric bath is not only the best method of applying general electrisation, but it also has great advantages for local treatment when the area to be treated is an extensive one, as, for instance, in sciatica, in hemiplegia, or in infantile paralysis, where the whole of one or more limbs may require electrical treatment.

The advantages of using a bath of water as a means of conveying electricity to a patient are as follows :

First, the water provides the best of conducting media because it adapts itself so completely to the surfaces of the body. Secondly, by moistening the skin uniformly and thoroughly, it lowers its resistance and favours the comfortable passage of the current through the skin.

Thirdly, all parts of the body are brought under treatment together, and this simplifies matters both when the body as a whole is to be treated, or when there are a number of separate areas all requiring attention.

Fourthly, because the warm water serves to keep the patient warm and comfortable during the time of the application. We may also include the stimulating action of the hot water upon the skin, for this is an additional therapeutic means that may often be of service in the cases which are being treated by electricity.

The bath itself should be made of porcelain or glazed earthenware, or it may be made of wood. The former is the best, as it is easily kept clean and has a good appearance.

A bath five feet six inches in length is long enough for the great majority of cases. For most female patients a five-foot bath is long enough.

The water in the bath should be agreeably warm, averaging 99° F., but it may be slightly warmer or cooler to suit the wishes of the patient. It is noteworthy that a difference of one or two degrees makes a great difference in the sensations of warmth felt by the patient at these temperatures. On this account a bath thermometer should always be used to ascertain and regulate the temperature. The bath should be so filled with water that when the patient lies in it the whole body and the shoulders may be covered.

Two electrodes consisting of metal plates are fixed at the head and foot of the bath, and they should always be kept clean and bright. These metal plates are provided with binding-screws to which the battery wires are attached (Fig. 56). Copper has a bright appearance, but zinc may also be used. It is of no use to have the electrodes plated with nickel or silver, as is sometimes done for appearance' sake, for the plating quickly leaves the positive pole. The electrode placed at the head of the bath is usually the larger, and may measure eighteen inches by twelve, that at the lower end of the bath being eleven inches by nine. In order to localize the current more or less in any part a movable paddle (Fig. 57), two or three inches square, connected by a long flexible wire to the foot-plate, may be used. It may either supplement the foot-plate, or replace it. The water in the bath should be deep enough to cover the plates.

The shoulders and back of the patient are kept from touching

the plate at the head of the bath by a rest made of wood, something like a picture-frame having pieces of webbing stretching

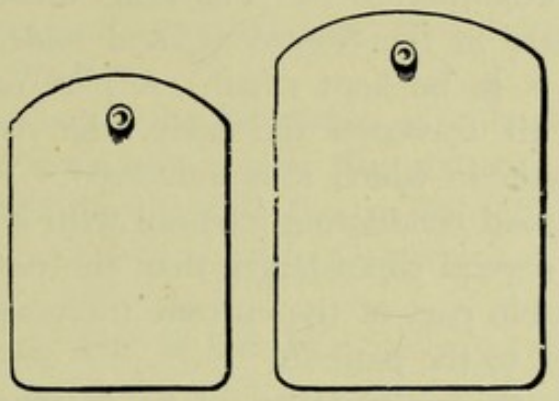


FIG. 56.—ELECTRODES FOR THE BATH.

across (Fig. 58). The light wicker fire-screens which are made to fit on to the backs of chairs are also convenient. Perhaps the

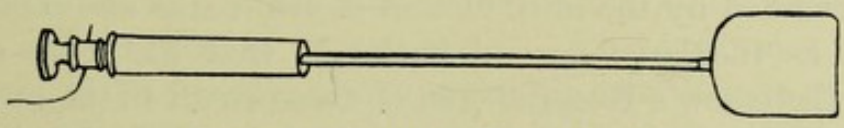


FIG. 57.—PADDLE ELECTRODE.

best head-rest is a broad strap of webbing stretched across the bath so as to support the neck. With female patients the bathing-dress gives additional protection to the skin of the back.

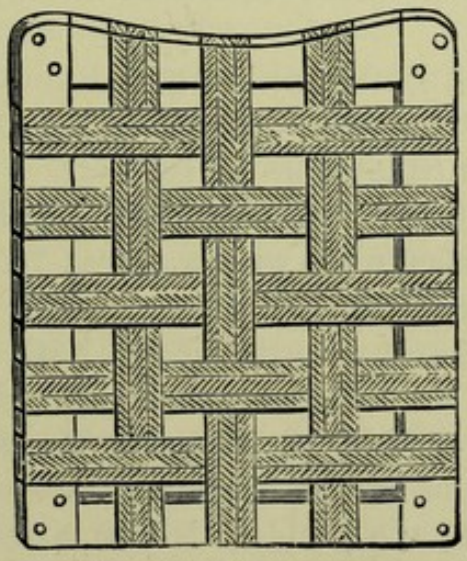


FIG. 58.—BACK REST.

The feet may be allowed to touch the electrode at their end of the bath, because the epidermis on the soles is thick enough

to take care of itself. If a patient is timid, the feet need not be placed in actual contact with the metal, but they should be kept in close proximity to it. The arms must be extended if they need a share in the treatment, and folded if the current through them is to be kept small. A part only of the total current in circuit traverses the body, the remainder passing through the water in which it is immersed. The water in the bath offers a broad conducting medium with a large transverse sectional area, several times larger than the patient, and therefore a considerable part of the current traverses the water and is altogether lost to the patient.

An electric bath was installed at St. Bartholomew's by the late Dr. Steavenson in 1882, and was for many years the only electric bath at a London hospital. Recently, one or two other hospitals have recognised their advantages and have taken them into use. The bath method of applying electricity has further been extended by the introduction of arm-baths and foot-baths, as well as the large general bath; so that there are now at St. Bartholomew's Hospital five of these small baths in regular use, to the great advantage of many patients, and with the effect of greatly simplifying the process of treatment; better results are now obtained in many conditions of disease by bath methods than was formerly the case.

The resistance in an electric bath will vary with its length, with the depth to which it is filled, and with the temperature of the water.

Dr. Hedley* has contributed largely to our knowledge of the physics of the electric bath, and his book should be studied by all those who are interested in the subject.

A porcelain bath five feet six inches long has a resistance of about 110 ohms, when filled with water at 100° F. to a depth of fifteen or sixteen inches.

A question of interest with the electric bath is the following :— How much of the total current passes through the patient, and how much is conveyed by the water ? The answer will depend upon the dimensions of the bath, and also on the quantity of water in the bath; the problem is best attacked by regarding the condition as one of a divided or branched circuit; the water being one, and the patient the other of two conductors; the pro-

* "Hydro-Electric Methods in Medicine." London: H. K. Lewis, 1896, Second Edition.

portion of current traversing each will depend upon their relative resistances. But the thicker parts (trunk) of the patient will convey more than the average, and the thinner parts (limbs) less, so that one cannot say that the patient carries such and such a fraction of the total.

M. Meylan* measured the resistance of a bath first with a patient immersed; secondly, with the patient removed, the water as before; and thirdly, with the patient removed, but with water added to bring the level up to that which it had when the patient was in it.

The measurements were as follows:

A. Water and patient	136	ohms resistance.
B. Water only	151	,, ,,
C. Water, with water added ..	130	,, ,,

By calculating out these figures he arrives at 1,360 ohms as the patient's resistance, and 1,033 ohms as that of the equivalent bulk of water added in experiment C. The resistance of the patient was rather greater than that of his own volume of water spread out in a layer over the area of the bath. The cubic measurement of an average-sized man is three cubic feet, or about eighteen and a half gallons.

If we compare the resistance of the water only, 151 ohms, with that of the patient, 1,360 ohms, we find that under the conditions of the particular bath the patient's body would be conveying about one-tenth of the current.

As the current which traverses the water does not affect the patient, and therefore may be considered as wasted, it follows that for economy of current the amount of water used in the bath should be no more than enough to cover the patient comfortably. On the other hand, a large volume of water retains its heat better for the time required for the bath, and should be preferred on that account, the waste of current being a matter of minor importance.

If salt or acid is added to the bath, the water becomes a better conductor than before, and the patient's share of the total current passing will be reduced. It is therefore improper to make such additions to the water. The duration of a bath should be from ten to fifteen minutes. The baths may be given on consecutive or on alternate days.

* *Revue Internationale d'Électrothérapie*, vol. v., p. 113 (November, 1894).

72. **The Electric Douche Bath.**—A douche of water may also be used to convey an electric current to a patient in a bath.

In the *Revue Internationale d'Électrothérapie* for June, 1894, Dr. Guyénot, of Aix les Bains, has described a method of applying electricity by means of douches. The current is led to and from the patient by two streams of water, the conductors being connected to the metal nozzles through which the water flows, and he insists upon the ease with which the jets of water can be made to carry the current to the whole surface of the body, or to any part of it, so as to give the effect of a general or of a localized electrisation. The article gives careful working details of the modes of applying either the battery current or the induction-coil current, and the account is well worthy of attention.

CHAPTER III

CAUTERY AND LIGHTING INSTRUMENTS—THE ELECTRO-MAGNET

The galvano-cautery—Batteries for cautery purposes—Accumulators—Wires and leads—Lamps—Batteries for lamps—The cystoscope—The antrum lamp—The panelectroscope—The electro-magnet—Ozone.

73. **Indirect Applications of Electrical Currents.**—The preceding chapter contains an account of the apparatus commonly used for the direct application of electrical currents to the body. The present one considers certain instruments for indirect application which are often valuable in medical practice. These are the galvanic cautery, the various forms of exploring lamp, and the electro-magnet as used for the removal of splinters of iron and steel from the tissues, particularly from those of the eyeball. A few notes on the medical applications of ozone are also added, although this agent has not yet been employed very largely for medical purposes.

74. **The Galvanic Cautery.**—The forms of galvano-cautery in common use are numerous, but their plan of construction depends upon one general principle. They consist of small loops of

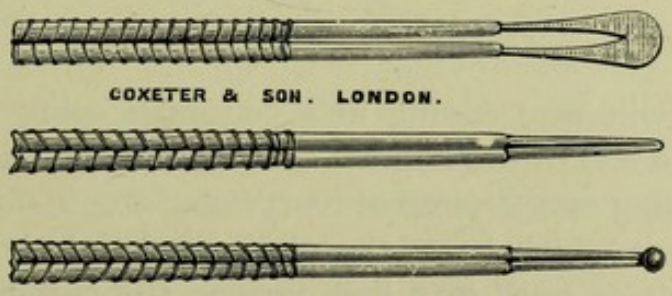


FIG. 59.—CAUTERY POINTS.

platinum wire mounted on straight or curved copper supports, which are insulated from each other by varnish and by turns of waxed thread, which also serve to hold them together to form a convenient stem (Fig. 59). These are made in various lengths

to suit different purposes, and they fit into sockets in a handle provided with binding-screws or other forms of connector, and with a key for opening and closing the circuit. The platinum

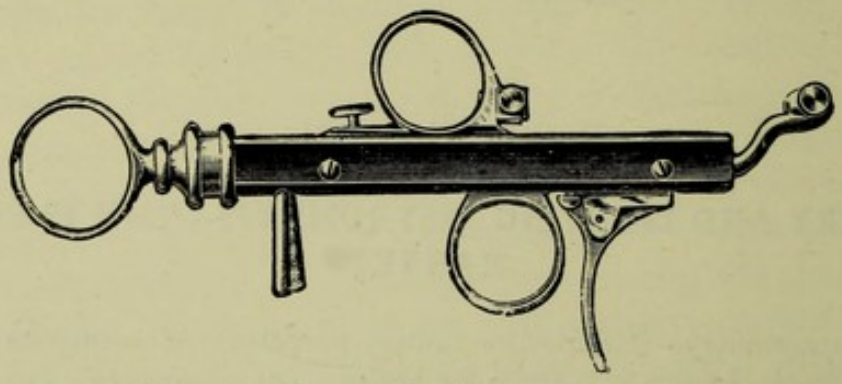


FIG. 60.—SCHECH'S CAUTERY HOLDER.

loops, having a relatively high resistance, become heated by the passage of the current. Figs. 60 and 61 show the usual

FIG. 61.—SIMPLE FORM OF HOLDER.

forms of holder. For most purposes the simpler handle is the most convenient.

For small-sized burners a very good handle is made in the shape of a metal pencil-case (Fig. 62). Connection is made

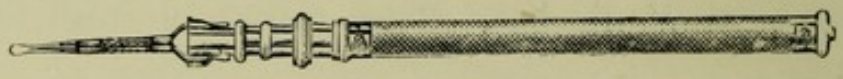


FIG. 62.—CAUTERY HANDLE.

through a twin wire ending in a concentric plug which fits a socket at the end of the handle, and the closing switch is a ring of metal sliding over a piece of ivory.

The current which heats the platinum points heats the rest of the circuit as well, in a less degree; the current, therefore, should only be left on when the cautery is in actual use.

Besides the simple loops of platinum wire there are others intended to serve as cutting instruments, which are made by hammering the platinum flat or by bending it in various ways. Where a large incandescent surface is required, a loop or spiral

of platinum supported in grooves on a porcelain mount is used, the porcelain becoming heated to redness as well as the platinum (see Fig. 63). Different thicknesses of platinum wire are used, and accordingly the current required to raise the burners to a red heat varies greatly in different cauteries.

Sometimes a long loop of wire is used as an ecraseur, being adapted cold to the part to be removed, and then heated, a screw being used on the handle for gradually tightening the wire loop when hot. Steel wire is sometimes used for these loops on account of its cheapness, but platinum is the best. It is as well to mention that the temperature of a cautery must not be allowed to rise above dull redness. At a white heat the cauterizing action is so rapid that searing of the surface does not take place, and hæmorrhage may follow as profusely as after division of the tissues by a knife. Many forms of cautery and mount will be found illustrated in the instrument-makers' catalogues.

FIG. 63.—CAUTERY WITH LARGER INCANDESCENT SURFACE.

The resistance of the cauteries just described may vary from 0·025 to 0·04 ohm.

The current required to bring the platinum loops to redness varies between eight or ten ampères for the smallest to upwards of twenty for the larger ones.

Still larger currents are required for a few cauteries, which have been constructed for special purposes.

In the prostatic cautery of Professor Bottini* the part to be heated consists of two strips of platinum, each 20 mm. × 8 mm., which lie side by side in the concavity near the beak of an instrument, which is shaped like a vesical sound. The current passes along one strip and returns by the other. The large mass of the platinum makes the resistance of the part to be heated remarkably low, about 0·0005 ohm, and consequently an immense current, amounting to fifty ampères, is required to raise it to a red heat. Such a current as this taxes any portable accumulator to the utmost. This instrument is used for the radical cure of the symptoms caused by enlarged prostate, and its use has been advocated in this country by

* *Brit. Med. Journ.*, 1891, vol. i., p. 1121. Description and figure.

Mr. Bruce Clarke,* who has employed it successfully on several occasions.

75. **Cautery Batteries.**—The batteries of small cells which are used in medical treatment are of no use for cautery currents.

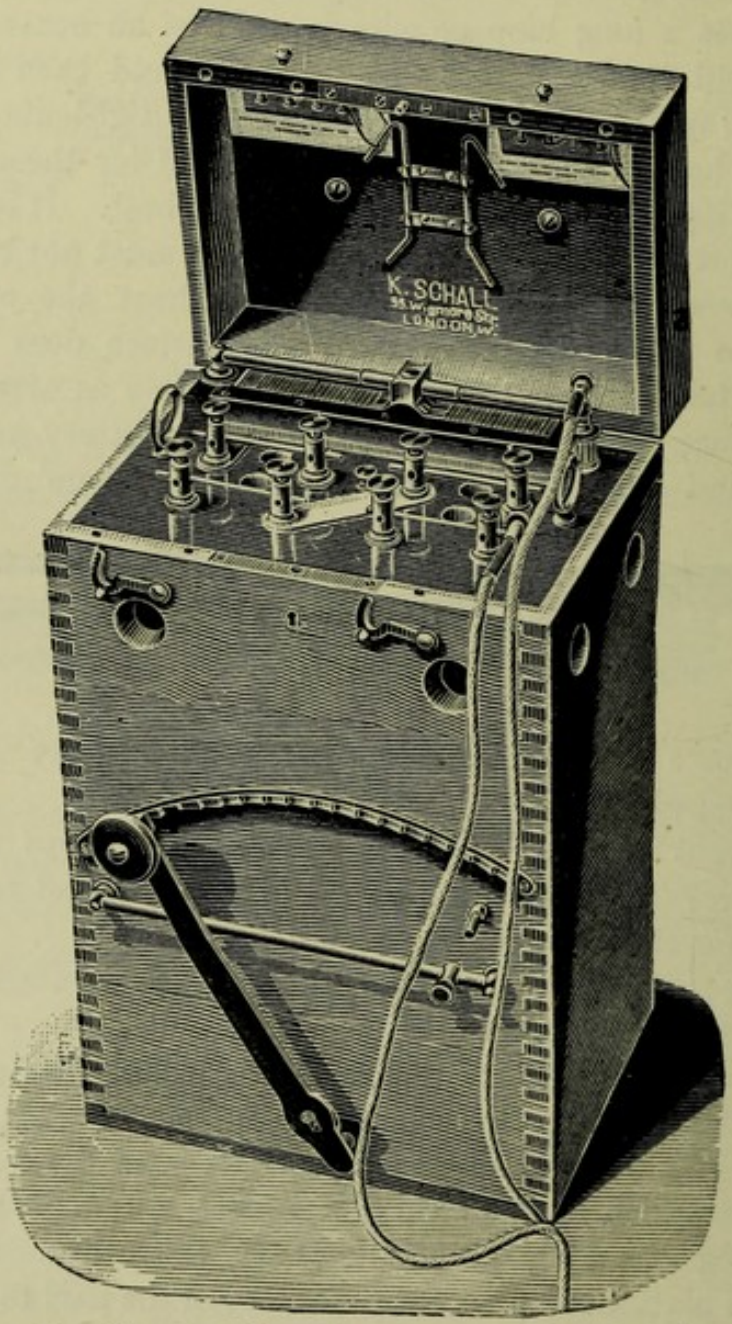


FIG. 64.—CHROMIC ACID BATTERY FOR ELECTRIC LAMPS AND GALVANO-CAUTERY.

They are designed for high electromotive forces and small currents, while for cautery purposes large currents and low electromotive forces are required. Chromic acid cells can be used for cautery purposes, because they are able to yield a large

* *Proceedings of the Medico-Chirurgical Society*, January, 1892

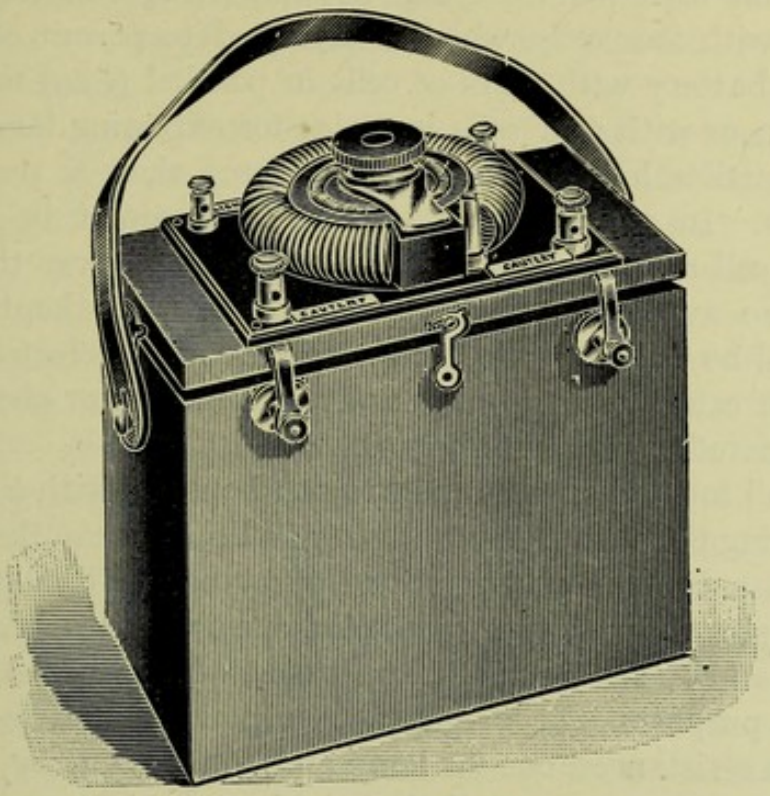


FIG. 65.—ACCUMULATOR FOR LAMPS AND CAUTERIES.

FIG. 66.—ACCUMULATOR FOR LAMPS AND CAUTERIES.

current for brief periods. Fig. 64 shows a special form of this battery with four cells, which is arranged to permit of use as a two-cell battery with pairs of cells in parallel (§ 29) for cautery purposes, or with four cells in series for exploring lamps, which need a rather higher electromotive force than is required for cauteries. In places where storage cells cannot be used this form of cell must be had recourse to, but wherever the electric mains are available or an accumulator can be kept in order these will be used in preference. The use of the electric lighting mains for cauteries and lamps and for accumulator charging will be considered in the next chapter.

A small four-celled accumulator can be fitted with a switch for rearranging the cells in two pairs in parallel. It can then be used either as a two-cell accumulator (four volts) of double cells for cautery purposes, or as a four-celled one for lamps (eight volts). Figs. 65 and 66 show such an apparatus, which is constructed for surgical purposes. It weighs fifteen pounds, and is provided with two resistances, one for lamp and one for cautery use. The connections are so arranged that the lamp resistance is in series with the lamp terminals, and the cautery resistance with the cautery terminals. The cells must not be left in parallel when the battery is not in use.

76. **Conductors.**—It is important to use thick copper wire conductors in cautery work because the resistance of the whole circuit being very low, that of the conductors becomes an important fraction of it, and may determine whether the cautery will be properly heated or not.

It may be useful to give an example here of the calculations to be made in arranging the apparatus for heating a cautery. Suppose that a cautery having a resistance of 0·04 ohm and requiring a current of 20 ampères is to be heated, and that the battery power available consists of two accumulator cells in series, each with an electromotive force of two volts, the internal resistance of each cell being 0·01 ohm.

To obtain a current of twenty ampères from four volts the total resistance in circuit may amount to 0·2 ohm. If proper leads are used their resistance will be 0·0014 ohm per metre. We will suppose each wire to be 1·5 metres in length, their total resistance will then be 0·0042 ohm. The necessary resistance in circuit in this case (resistance of battery, of leads, and of cautery) therefore amount to $0{\cdot}02 + 0{\cdot}0042 + 0{\cdot}04 = 0{\cdot}0642$, or

say 0·065 ohm. This leaves a margin for faulty contacts and for rheostat of 0·135 ohm, and the cautery would be adequately and easily heated.

But now suppose that the leads are of a size having a resistance of 0·04 ohm per metre. This will give a total resistance in circuit of 0·02 + 0·12 + 0·04 = 0·18 ohm, leaving a bare margin of 0·02 ohm for faulty contacts. This would be insufficient, as there are several points of contact, and a small degree of oxidation or tarnishing at any one of them would prevent the cautery from heating, add to which there would in all probability be a considerable amount of heating in the leads, which would certainly increase their resistance, and might destroy their insulation. These examples show the importance of using conducting wires with plenty of copper in them, and of keeping all contacts and binding screws scrupulously clean and bright. A regulating resistance must always be included in the circuit when a cautery is to be heated, for if this precaution is neglected there will be much trouble from overheating and fusing of the platinum loops.

An open helix of thick German silver wire with a sliding contact piece is generally used for a resistance, and one made after the pattern shown in Fig. 66 may be used. As will be seen from the calculations in the preceding paragraphs, its resistance in ohms should be quite small.

77. **Lamp Instruments for Diagnosis.**—Small incandescent lamps have been adapted to laryngoscopes, ophthalmoscopes,

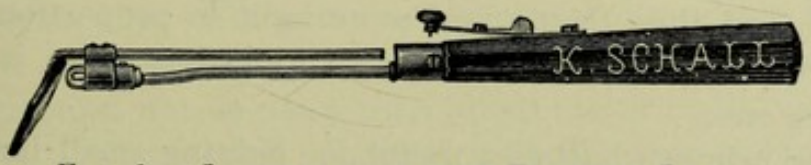


FIG. 67.—LARYNGOSCOPE WITH ELECTRIC LAMP.

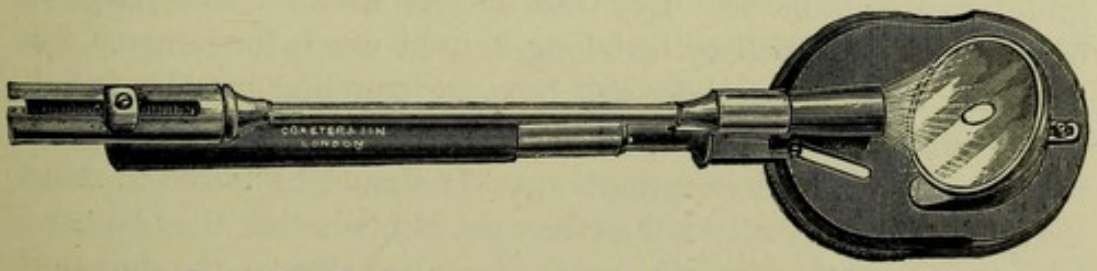


FIG. 68.—OPHTHALMOSCOPE WITH ELECTRIC LAMP.

otoscopes, vaginal specula and other instruments (Figs. 67 and 68). They are not used very universally, because in many

cases the maintenance of the battery is troublesome, and because other sources of illumination are sufficient.

On the other hand certain new exploring instruments have come into use whose value depends entirely upon the principle of the electric lamp. The cystoscope and the antrum lamp are examples of this form of lamp instrument. The small lamps used in diagnosis are of about one candle power, and vary a good deal in their resistance (5 to 20 ohms), and therefore the electromotive force required to bring them to incandescence varies also. If the filament is slender, or if it is long, their resistance is high; if it is short or thick, their resistance is less high. A long slender filament may require ten volts or more to light it properly, while a shorter one may glow with four volts. The rate of consumption of energy by an incandescent lamp is about four Watts per candle. Thus if a ten-volt lamp absorbs 0·4 of an ampère, a six-volt lamp would require 0·7 ampère to give the same light. When the current is supplied from a portable battery it is best to use the higher voltage lamp for the sake of the advantage of having to provide a smaller current, but it would be a convenience if all small surgical lamps were made for one and the same voltage. As the four-cell accumulator of eight volts is the type of battery most generally useful, lamps should be chosen as far as possible to incandesce brightly with this electromotive force.

The so-called "cold lamps" are lamps which can be brought to a high degree of incandescence without destruction of the filament, and thus they afford more light in proportion to the heat given out, but the word cold as applied to them is merely a relative one.

Among primary batteries useful for lighting small lamps the chromic acid cell is convenient if no means of recharging accumulators are available. Dry cells may be used for this purpose, but do not keep well or last long if used much for lamps. Six dry cells fitted in a plain oak box are supplied by Mr. Schall with a simple form of rheostat, and they may be trusted for a fair number of short examinations. It should be borne in mind that dry cells gradually fail as they get old, whether they be used or not. From three to six months may be taken as the duration of usefulness with dry cells. An improved form of Leclanché battery, the "Sack" cell, has also been introduced, and answers well for lamps if portability is not required.

If accumulators are used small ones may be had for the sake of portability. Small accumulator batteries are put up by several electrical instrument-makers, and serve well for surgical lamps (see Figs. 65 and 66). The small sizes naturally require recharging more often than the large ones, but this is not an objection, because all accumulators are better for being recharged at least once a week, and the capacity of the small cells is sufficient for lighting a cystoscope or similar lamp for several hours. If the small accumulators can be recharged at home from the mains without trouble they are extremely convenient, but this convenience is lost if they have to be sent away every time to be recharged.

The introduction of electric ignition for motor-cars has done much to improve the manufacture of small accumulators and to familiarize medical men with their management. The small two-celled accumulators used in motor-car work may be employed for surgical exploring lamps, if two of these batteries are joined in series, to give a pressure of eight volts. A small resistance for regulating purposes is desirable to prevent over-running of the lamps. For galvano-cauteries these accumulators are rather small, but they may be used at a pinch for the purpose, the two batteries should then be connected in parallel.*

As the different forms of small lamp vary a good deal in their resistance a regulating resistance in the circuit is necessary to compensate for these variations, as without it some lamps would be overheated and would quickly be destroyed. Suitable resistances are supplied with many of the types of portable accumulator now in the market. The resistance required for regulating the lamps need not be more than about six or eight ohms. As the current to be carried is only about half an ampère in a well-made lamp the resistance is easily made of a few turns of fine German silver wire. Resistances are equally important for cauteries, but there they have to carry large currents, and must be made of thick wire; however, their total resistance need not be so great, for a variable resistance of half an ohm is sufficient to modify very greatly the current in a cautery circuit (see § 76).

Electric lamps are made in a variety of forms with bull's-eye lenses or reflectors for medical use. They may be had on standards, affixed to wall-brackets, or as hand-lamps, and many

* A good cell is made by the Electric Ignition Co., of Sampson Road North, Sparkbrook, Birmingham, and 11, Nassau Road, Barnes, S.W.

patterns will be found illustrated in the instrument-makers' catalogues. The Nernst* lamp, combined with frosted or opal glass, gives a bright and uniform illumination.

A convenient form of exploring-lamp is shown in Fig. 69. It is designed in such a way as to be kept clean and aseptic without any difficulty. It may be left in the antiseptic solution until required for use. The attachment to the leads is by a

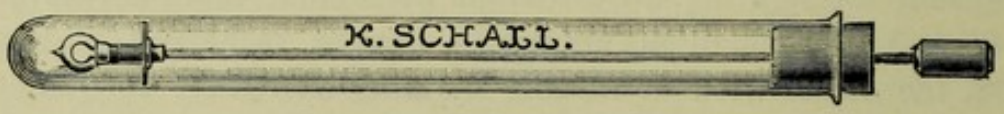


FIG. 69.—EXPLORING LAMP.

double socket fitting, one wire making contact with the periphery of the tube which carries the lamp, and the other with an insulated lead which passes down the centre. The enclosing tube of glass prevents any burning of the tissues with which it might come in contact during an operation. The stem passes through an indiarubber cork.

A head-lamp is useful in many surgical operations. Its present

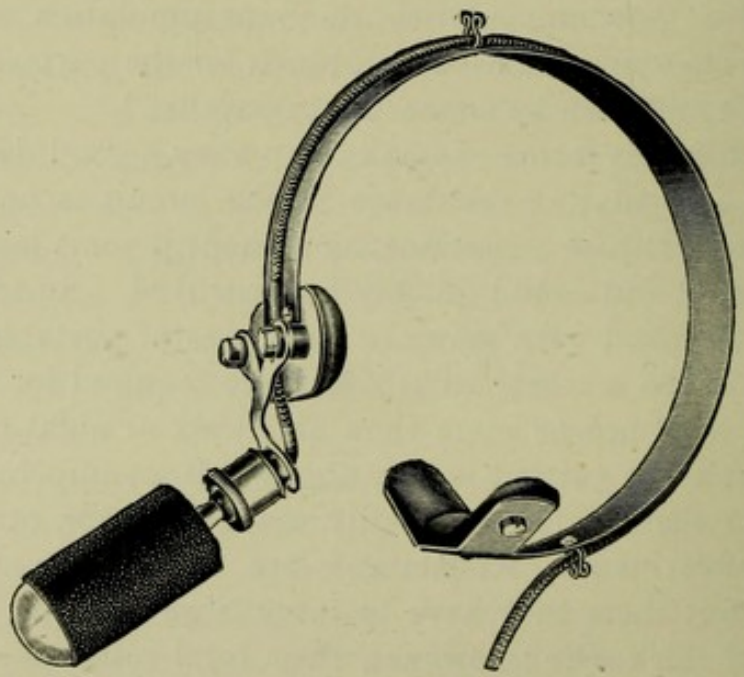


FIG. 70.—TROUVÉ'S HEAD LAMP.

form and arrangement is shown in Fig. 70. It was originally designed by Trouvé, and has been modified by subsequent experimenters.

* The Nernst lamp has a short rod of the oxides of some of the rare earth group of metals in place of a carbon filament, and glows with a whiter and more brilliant light.

One interesting form of lamp-instrument has a rod of glass along which the light of a lamp is conveyed by a series of internal reflections. It is quite cool, and may be used for numerous purposes of exploration (see Fig. 71).

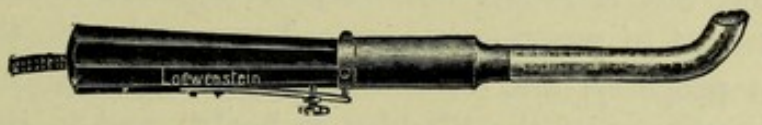


Fig. 71.—Glass Rod Lamp.

78. **The Cystoscope.**—This is an instrument for examining the interior of the bladder, and is one of the most important of all the electric-lamp instruments.

It consists of a beaked sound containing a telescope with which the wall of the bladder is viewed through a reflecting prism of rock-crystal. A lamp protected by a metal cap forms the beak of the instrument, and throws its light upon that part of the bladder-wall which is in the field of view of the telescope. By rotating the instrument the different parts of the mucous membrane can be brought into view, and the direction of the vision is indicated by a small knob fixed upon the eyepiece of the instrument.

Fig. 72 shows the simple cystoscope in its modern form, but of late years there have been many additions to it. Thus it can be modified so that the optical part may be removed, leaving the outer tube in place for washing out the bladder, while in another form one or two catheters can be passed down the instrument

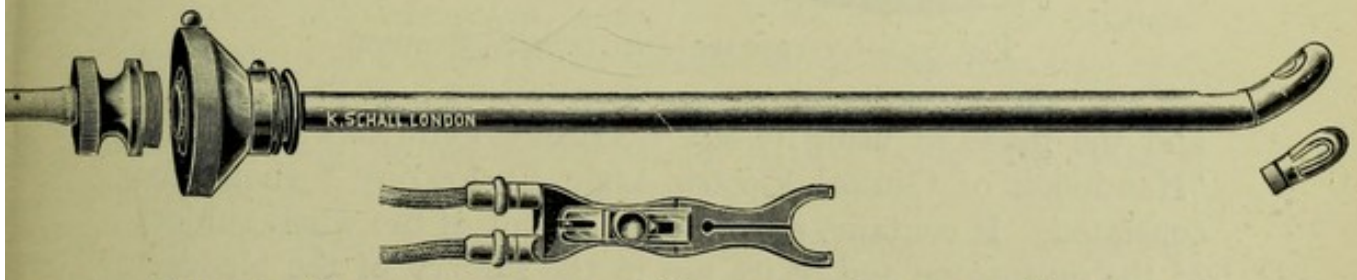


Fig. 72.—Cystoscope, showing Details of Lamp and Model of Attachment of Conductors.

for the same purpose, or for catheterizing the ureter. There are also forms of cystoscope which enable two persons to view the bladder at the same time, and this is very useful for purposes of demonstration, and finally Professor Nitze has devised a cystoscope with photographic attachment.

Modern cystoscopes are so made as to allow of sterilization by boiling without injury. The attachment shown on the left of the eyepiece is screwed on to protect the telescope during the process. A separate instrument is made for viewing the posterior wall of the bladder, but it is not nowadays considered necessary. A certain amount of practice is required to enable one to use the cystoscope properly, and to recognise the appearances of the mucous membrane of the bladder in health and in its various morbid conditions. The dummy bladder (Fig. 73) is useful for practice at the beginning. For a full account of the instrument

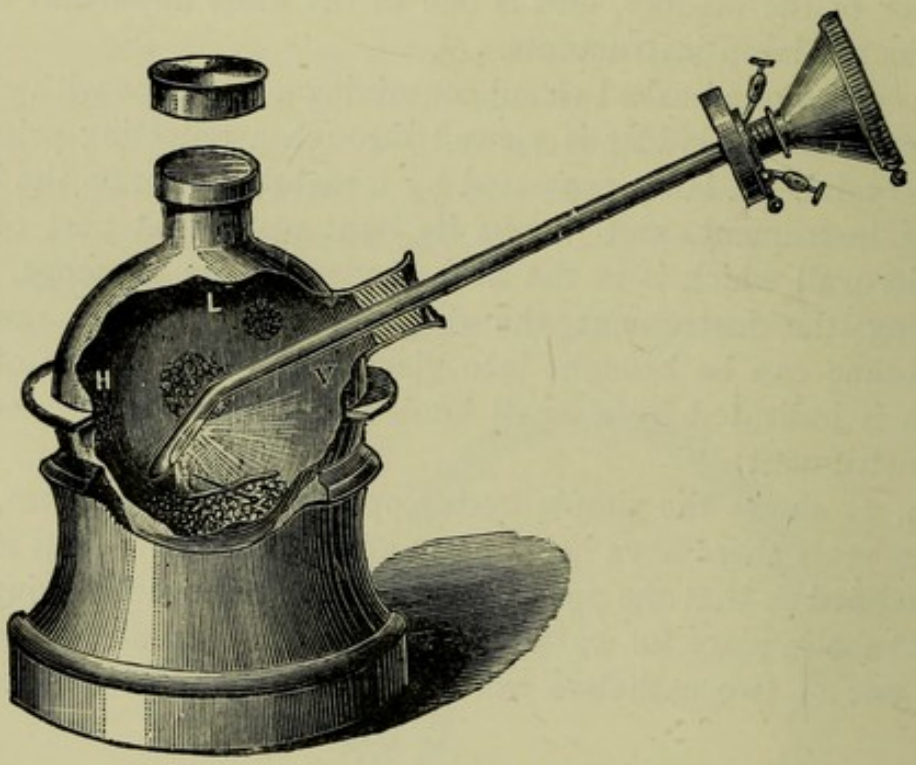


FIG. 73.—CYSTOSCOPE AND DUMMY BLADDER.

and the mode of using it Mr. E. Hurry Fenwick's admirable 'Handbook of Clinical Electric Light Cystoscopy'* should be consulted. It contains a complete account of the whole subject of the cystoscope and of its use in the surgery of the bladder. The student may also consult a valuable paper in *The Practitioner* for July, 1905, by Mr. David Newman on 'The Teaching of Cystoscopy, with special reference to the use of the cystoscope in the diagnosis of renal disease.' This paper, like Mr. Fenwick's handbook, contains many instructive illustrations of cystoscopic appearances in various morbid conditions.

* J. A. Churchill, London, 1904.

A general anæsthetic is not necessary for a cystoscopic examination, although it may be convenient to employ one in some cases. Mr. Fenwick recommends that a drachm of a 20 per cent. solution of cocaine may be added to six ounces of warm boracic lotion or of normal saline solution and injected into the bladder. The bladder must contain a certain amount of clear urine or clear fluid if a proper view of its walls is to be obtained. Five or six ounces is recommended by some writers as a proper quantity, while others advise eight ounces. If the urine or fluid in the bladder is even slightly turbid the view is much obscured. A very little blood is quite sufficient to interfere with proper vision, and when any blood is present it is quite useless to try and force matters by over-running the lamp in order to produce more light. The little lamps in cystoscopes are often grievously ill-treated in this way. but the difficulties in using the instrument are almost always due to turbidity in the fluid. When this is quite clear the beauty and transparency of the resulting picture is most striking.

If too little fluid be present the beak of the cystoscope may become buried in the loose folds of the bladder wall, and there will be no light ; moreover, in that case the mucous membrane may be burned. For the same reason the cystoscope must be pushed well home into the bladder and kept there. If it be allowed to work out at all, as it sometimes tends to do, the beak may become engaged in the prostate, and then again nothing will be seen, and the mucous membrane may be burned. The heat of the lamp is unimportant when it is surrounded by a volume of water, but when the lamp lies close against the mucous membrane there is no proper circulation of fluid round it, and it grows hot and will burn if held long in one place. So, too, if the instrument is pushed in too far it may come into contact with the posterior wall of the bladder with the same result.

Dr. Newman, in his paper, has the following remarks on the points required in a cystoscope. It should have : '(1) Comparatively small lumen of the stem, so that the instrument may be introduced without injury to the urethra or the neck of the bladder ; (2) large field of vision and a clear view ; (3) easy means of clearing the field should it become obscure, without removing the stem of the instrument from the bladder ; (4) good illumination without danger of scalding the mucous membrane of the bladder ; (5) ease in sterilizing the instrument ; (6) facility in

emptying the bladder should there be clamant call to urinate, without necessitating the removal of the cystoscope; and (7) ability to demonstrate to a second observer the object seen.' He then describes and illustrates a form of cystoscope which combines all these requirements.

79. **Electric Endoscopes.**—A universal lighting apparatus was introduced by Leiter, of Vienna, under the name of the pan-electroscope (Fig. 74). It consists of a lampholder or lantern with a handle and a reflector. The light of the lamp in the lantern is projected along a tube which is inserted into the part

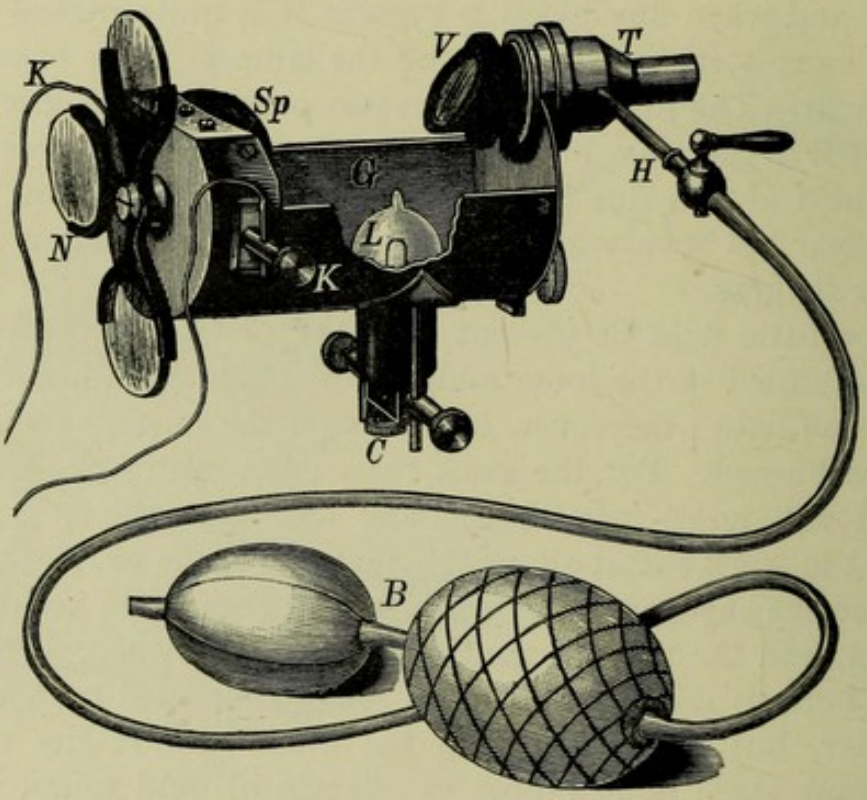


FIG. 74.—FENWICK'S IMPROVED PANELECTROSCOPE.

to be examined. Tubes of various sizes are adapted to the instrument, which is used mainly as an urethral endoscope, but is also arranged for the examination of the ear, the pharynx, the œsophagus, and stomach, and for the rectum. In the figure, *C* is the point of attachment of a handle, *L* is the lamp, *Sp* the mirror which throws the beam of light along the axis of the tube *T*, *K* the points of attachment of the conducting wires. The pump *B* and the stopcock *H* are provided as a means of inflating the urethra with air in order to permit a more thorough examination of its surface. *V* is a glass window closing the tube.

In the endoscope shown in Fig. 75 the light of the lamp is projected along the tube by means of a prism placed directly above the lamp, which is enclosed in the upper part of the handle. The endoscope used for the rectum is called a proctoscope, and

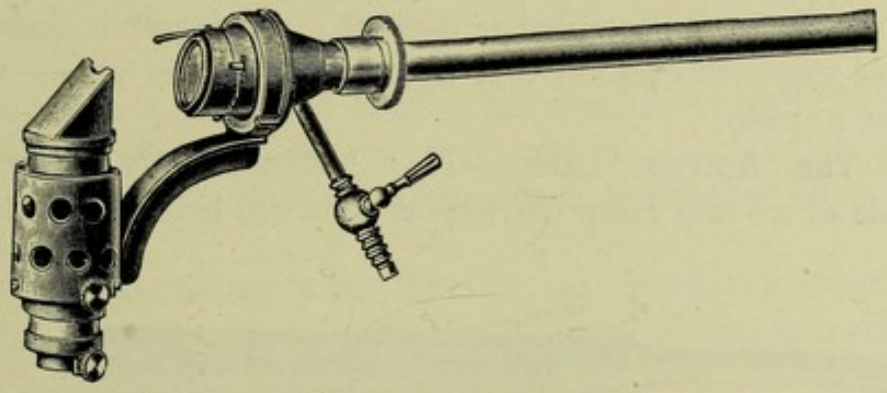


FIG. 75.—SIMPLE FORM OF INFLATING URETHROSCOPE.

has a lamp inside the tube arranged much as in Fig. 76, which shows a similar lamp adopted to a vaginal speculum. The proctoscope has proved to be a valuable instrument. It is

FIG. 76.—VAGINAL ENDOSCOPE.

provided with a lens for closing its external opening when in use, and with a stop-cock for irrigation, a plug for closing its distal end during introduction, and a fine forceps on a long wire stem for carrying cotton-wool swabs.

80. **Transillumination.**—The ease with which small electrical lamps can be brought into close contact with the tissues without fear of burns has led to the invention of new methods of examination which may be conveniently grouped together under the name of transillumination. These methods depend upon the translucency of the tissues; thus a lamp placed in the mouth will light up the tissues of the nose so that these appear luminous and the nasal passages may thus be viewed in a darkened room by the light transmitted.

Czermak in 1858 discovered that the larynx could be examined when illuminated from without by a beam of light concentrated

upon the external surface of the neck at the level of the thyroid cartilage, and Voltolini in 1888 found that the bones of the face could be illuminated by the light of an electric lamp held in the mouth.

The exploration of the antrum of Highmore by means of a lamp placed in the mouth has excited a considerable amount of interest since the publication by Heryng of his paper on the subject in 1889.

81. **The Antrum Lamp.**—This instrument (Figs. 77, 78) consists of a small lamp carried on a curved handle, and having

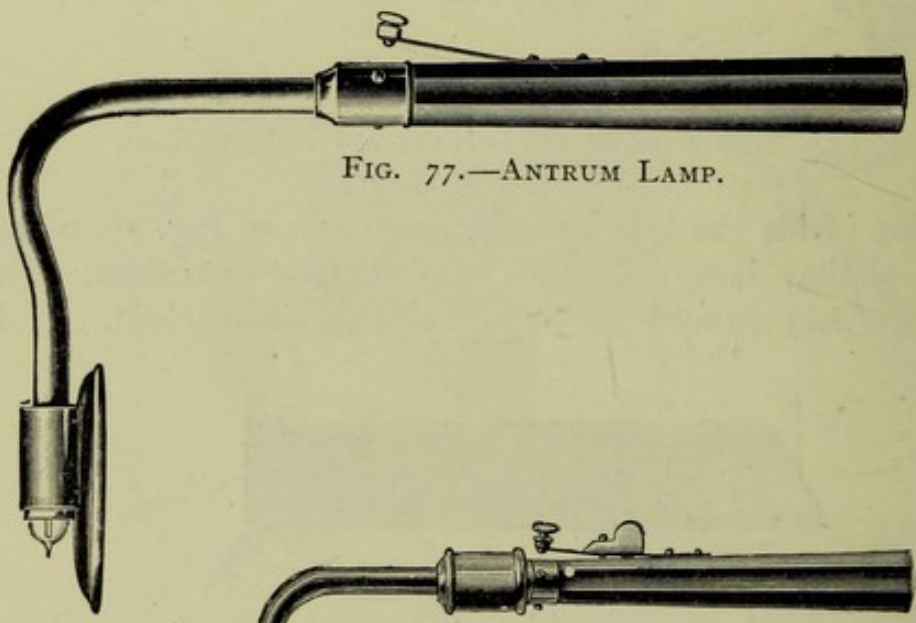


FIG. 77.—ANTRUM LAMP.

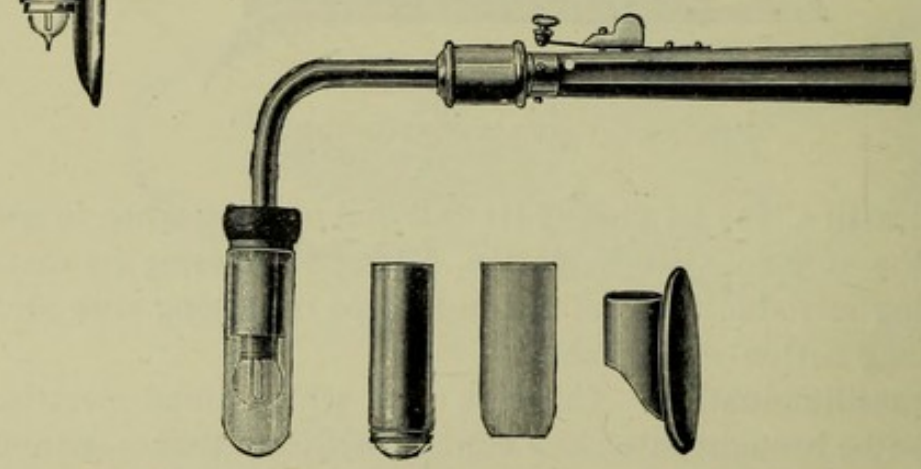


FIG. 78.—ANTRUM LAMP WITH VARIOUS LAMP CAPS.

a plate of ebonite to protect the tongue. Dr. Brown Kelly* recommends the use of a series of cylindrical caps which are

* 'Transillumination of the Antrum of Highmore,' *British Medical Journal*, March 25, 1905, with special coloured plate.

'Contributions to the Pathology and Diagnosis of Certain Affections of the Antrum of Highmore' (Glasgow: A. Macdougall, 1905).

slipped over the lamp, and have openings at the end or side to suit the different applications of the instrument. To use the antrum lamp the patient must be brought into a darkened room, the lamp is introduced into his mouth, and the lips are closed over its stem; when the current is then turned on the face becomes lighted up by a red glow. If one antrum contains pus a dark shadow is seen on the corresponding side, which is most perceptible just below the eye. The lamp used should have an illuminating power of three or four candles. For details of the use of the antrum lamp in practice see one or other of Dr. Kelly's papers.

82. **The Gastro-diaphane.**—This is a transillumination contrivance for lighting up the stomach from within in order to enable an opinion to be formed of its size and position when viewed from without. It consists of a stomach-tube of soft

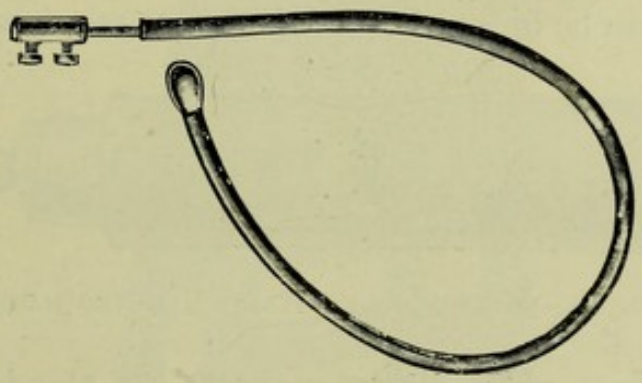


FIG. 79.—THE GASTRO-DIAPHANE.

rubber carrying a pair of wires, and at its end there is a small electric lamp which is protected by an outer cap of glass. Usually the instrument is fitted with a channel for conveying water into the stomach. To use the apparatus the lamp is passed into the stomach; the patient must be in darkness; when the light is then turned on a luminous glow is seen in the region of the stomach, and the appearance of this in normal individuals should be known in order to judge of alterations due to disease. The stomach should contain eight ounces of water, but no food. Herschell* states that the illuminated area of the stomach may be obscured by liver, by intestine containing fæces, or by tumours, and that the lower part only of a normal stomach is translucent, but if the whole stomach is illuminated gastro-

* 'A Manual of Intragastric Technique' (London: H. J. Glaisher, 1903).

ptosis is most likely present, and in this case the illuminated area does not move with respiration. In dilatation of the stomach the upper border of the stomach is not seen, and respiratory movements are present.

83. **The Electro-magnet.**—In certain cases this instrument is very valuable for the removal of fragments of iron or steel from the various parts of the body, and most especially from the eye. If the particle of iron be very small, or if it be fixed at all firmly in the tissues, a magnet is not likely to remove it. But if the piece of metal be larger, and if it be lying loose, as, for example, in the interior of the eye, it may be withdrawn most successfully by a magnet. Fig. 80 shows Hirschberg's hand electro-magnet, which can be wound to suit an 8-volt accumulator, and then takes 7 ampères, or for use on electric light mains at 100 or 200 volts, the current on these circuits being 0·5 and 0·25 of an ampère respectively. It is fitted with pole pieces both straight and curved, and can be brought up to the eye as required.

FIG. 80.—HIRSCHBERG'S HAND ELECTRO-MAGNET.

Of late years giant electro-magnets on stands have been employed by Professor Haab and others. These instruments are unwieldy, and difficulties are sometimes experienced in manipulating them, but they are popular among ophthalmic surgeons at the present day. In a recent number of *The Ophthalmoscope* * the arguments in favour of hand-magnets and of giant magnets are discussed in three valuable papers by Professor J. Hirschberg, Professor O. Haab, and Professor S. Snell. The former appears to prefer the hand-magnet, though he speaks of the giant as having considerably increased the number of curable cases. Professor Simeon Snell, whose special acquaintance with the use of electro-magnets dates back to the year 1881, points out that the results from the use of Haab's magnet have by no means overwhelmed those of the hand-magnet, and gives it as his opinion that 'the value of the hand-magnet should always be set forth whatever be the views of those employing the large

* February 1, 1905.

magnet.' The student should consult the journal just quoted for further information on the subject.

Although the action of huge electro-magnets in attracting large pieces of iron from a distance may impress the casual observer, it must be borne in mind that there is a limit to the

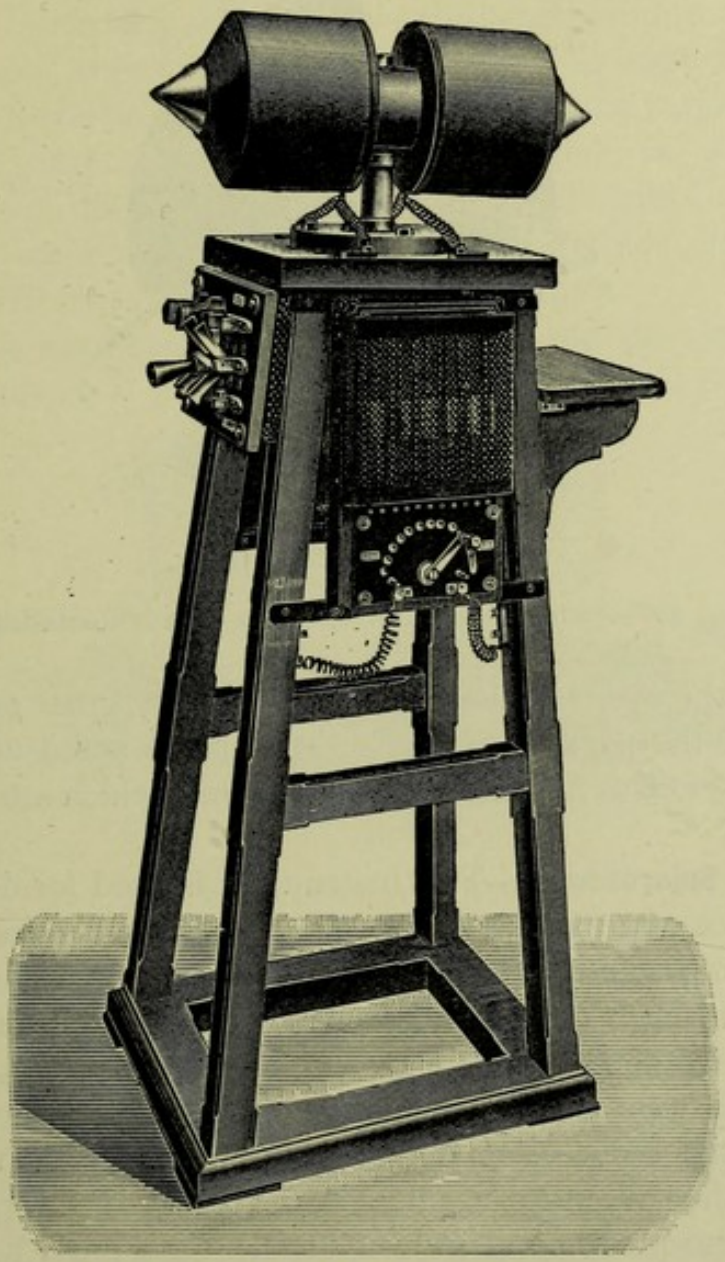


FIG. 81.—HAAB'S ELECTRO-MAGNET.

number of magnetic lines which can be crowded into a mass of iron, and that any increase of current beyond that by which the iron core is magnetically saturated is of small advantage. Thus it is probable that any electro-magnet carrying a sufficient current to produce magnetic saturation will be equally effective

in attracting small particles of iron, and that for the small fragments which occur in the globe of the eye there can be no advantage in using very large instruments, because the attractive effect is due to the magnetic field at the pole-tip which is pre-

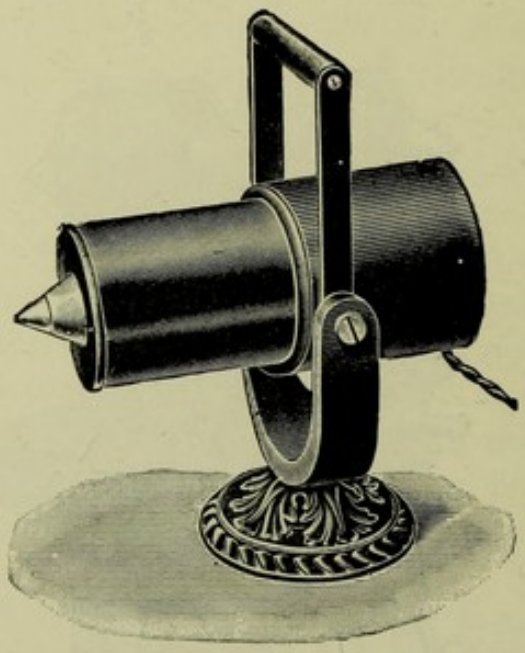


FIG. 82.—PROFESSOR SCHLOESSER'S ELECTRO-MAGNET.

sented to the eye, and depends also to a very great extent upon the size of the particle of iron or steel to be acted upon. It is the small particles rather than the large ones which are so difficult to extract.

84. **The Sideroscope.**—This instrument is used for determining the presence of a particle of iron or steel in the tissues. It is an invention of Professor Hirschberg, and consists of a fine magnetic needle carrying a mirror and suspended by a delicate silk fibre. A lamp is arranged so that a spot of light falling upon the mirror is reflected upon a horizontal scale. It is brought to the zero mark of the scale, and the patient's head is then made to approach the suspended needle. A deviation of the spot of light indicates the presence of iron or steel. Care must be taken to avoid fallacies arising from magnetic bodies in the clothing of the patient or the operator.

85. **Ozone** has been proposed for use in therapeutics by many writers, but hitherto no striking advantages have been proved to follow its use. Indeed, it has been shown to be noxious when present in the air in any but the smallest proportions. The presence of less than a milligramme of ozone per litre was found

by Dr. Bordier to prove fatal to a guinea-pig in half an hour, and the results found post-mortem indicated that the ozone acted as a violent irritant to the respiratory tract.

Ozone in moderate quantities is found in the neighbourhood of all high potential electrical apparatus when in action, being produced by the effect of the brush discharges upon the oxygen of the air. Generally some nitric oxides are produced at the same time, and these doubtless increase the irritant action of the ozone. Nevertheless ozone has been tried in various affections of the respiratory tract, as, for instance, in whooping-cough and in phthisis, but the results obtained cannot as yet be regarded as conclusive, though it has been strongly recommended by French writers for the first of these disorders.

Ozone has also been recommended for the disinfection of crowded rooms, as it possesses very marked oxidizing properties.

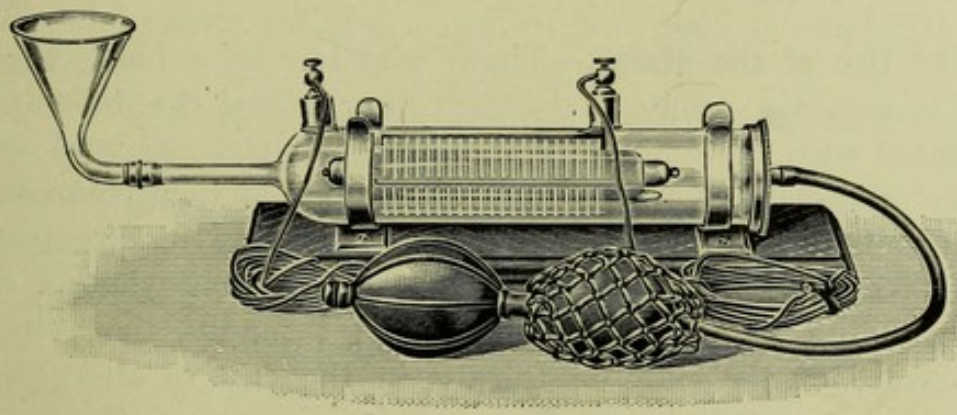


FIG. 83.—OZONE APPARATUS.

Fig. 83 shows an apparatus for producing ozone by means of induction coil discharges.

In the best form of apparatus air is blown through a channel between two surfaces of glass whose other surfaces are covered with a layer of tinfoil, and are connected to the terminals of an induction coil. A convenient form for the apparatus to take is that of two concentric cylinders, the one fitting inside the other with an air-space between. When the apparatus is in action a violet glow is seen in the air-space, and the air blown through it comes out with the characteristic smell of ozone. For purposes of inhalation it is preferable to use a cylinder of compressed oxygen rather than air blown through by a bellows for the source of the ozone, because the production of the oxides of nitrogen is prevented by this method.

CHAPTER IV

THE UTILIZATION OF THE ELECTRIC LIGHT MAINS

Regulation of pressure and of current—Use of shunt circuits—Direct current—Applications to patients—Accumulator charging—Galvano-cautery methods—Alternating current—Transformers—Accumulator charging—Rectifiers—The aluminium cell—Electric lamps in therapeutics—Dangers.

86. **The Use of the Mains.**—Those who live in a place where there is a public supply of electricity are spared the difficulties associated with the maintenance of primary batteries, and only require to know the capabilities of the supply at their command, and how best to adapt it for their professional requirements. For this it is necessary in the first place to know whether the public supply is direct or alternating; secondly, the voltage or pressure of the supply; thirdly, in the case of alternating current, the periodicity or frequency of the alternations. In an Appendix a list is given of the public supply stations in Great Britain and Ireland, with particulars of these details. Much progress has been made in the design of medical apparatus for use on electric light mains, both for the direct and alternating systems of supply.

The difference between direct and alternating current is that in the former there is a steady flow of current from the one conductor or lead through the lamp (or other appliance) to the other. The one wire is always positive, the other always negative. In the alternating supply the current flows in a series of pulsations, first in one direction and then in the other, each wire being in turn either positive or negative. The pressure at which electric lighting currents were originally supplied to houses was usually 100 volts, in some places 103, 105, or 110. At the present time a general change to 200, 220, and 240 volts is taking place, with the object of saving expense in mains. At 200 volts a given

current represents twice as much energy as the same current at 100 volts, so by doubling the voltage of supply the conductors are enabled to carry a double load without the need for increasing their sectional area, as would be necessary if they had to carry double the magnitude of current. There is no advantage at all to the consumer from the higher voltage, but rather the reverse, but the advantage to the supply companies in the saving of capital outlay on copper for mains is considerable.

In the succeeding sections the best ways of managing the current from the mains will be considered in their various applications in medical practice.

First it will be convenient to consider methods suited to a direct current (D.C.) supply, and secondly those required in a place supplied by alternating current (A.C.).

The uses to which the current from the mains may be applied are as follows :

1. To replace medical batteries and coils in applications to patients.
2. To provide sinusoidal current for purposes of treatment.
3. To charge accumulators.
4. To illuminate the small lamps used in diagnosis, such as cystoscopes, antrum lamps, etc.
5. To heat galvano-cauteries.
6. To work large coils for high-frequency and X-ray applications.
7. To drive motors for statical machines or for surgical and dental drills, saws, and trephines.
8. To operate arc lamps and other special lamps for the applications of light in treatment.

87. **Reduction of Pressure—Resistances.**—In almost all applications of the current to medical practice the first need is for a means of reducing the pressure. The pressure of supply is too great for many of the medical purposes just enumerated. In order to reduce the pressure resistances are employed, for by means of the resistances in a circuit the magnitude of the current in the circuit can be regulated. Thus a resistance of 100 ohms in a circuit of 100 volts will prevent the current from exceeding one ampère, and a resistance of 100,000 ohms will cut down the current to one milliampère, and so on.

It is important to distinguish between the effect of a resistance in cutting down the current in a circuit, and its effect in lowering

the voltage in a circuit or portion of a circuit. In § 28, when treating of the internal resistance of cells, an attempt was made to draw this distinction, and it may now be repeated that the effect of a resistance upon the voltage in any part of a circuit is a relative one—that is to say, the fall of volts in a part of a circuit, such as a resistance, depends upon the resistances in the other parts of the circuit, and may be estimated by comparing the resistance of the part under consideration with the resistance of the rest of the circuit. For instance, take a resistance of 99 ohms interpolated in a circuit of 100 volts, when the resistance of the remainder of the circuit is very small, say, for purposes of illustration, one ohm, then the drop of volts in the resistance will be 99 volts. But if four such resistances be inserted in different parts of the same circuit then the drop in volts at each resistance will no longer be 99 volts, but will be one quarter of that amount, and the fall in the potential from 100 to 0 will take place in four steps of about 25 volts, one at each resistance. It follows from this that a resistance intended for regulating the voltage in any part of a circuit must be made proportional to the resistance of the circuit to be regulated. If the resistance of the part to be regulated is 50 ohms, then a resistance of 50 other ohms will half the voltage acting on it, but a resistance of 50 ohms will not equally half the pressure if the other part has a resistance of 950 ohms, for in this case the fall in volts at the first resistance would only be one-twentieth of the total electromotive force of the circuit, while the second portion would bear a pressure of nineteen-twentieths of the total. A resistance which is suited for the regulation of the current of a lamp will not serve to regulate current through the human body. In the first case a few ohms will suffice, in the latter several thousand ohms are necessary.

It was stated in § 25 that the energy expended when a current passes through a resistance appears for the most part in the form of heat. Resistances, therefore, become heated when in use, and the heating effects must be carefully borne in mind and the resistances designed to carry, without excessive heating, the currents they are intended to regulate. A resistance suitable for a current of a few milliampères might be burnt out if a current of one ampère were passed through it. From their cheapness and convenience incandescent lamps are often useful for resistances as they are not injuriously affected even by great heating,

and in almost all resistances for medical use an incandescent lamp forms part of the circuit, being combined usually with a coiled wire resistance which admits of adjustment. On a circuit of 100 volts an eight-candle power lamp will cut down the current to about 0·3 of an ampère, a sixteen-candle lamp to 0·6, while a thirty-two will allow 1·2 ampères to pass. As a rough approximation the resistances of incandescent lamps when hot (§ 23) may be taken as follows : For 100 volts—an eight-candle lamp, 320 ohms ; a sixteen, 160 ohms ; a thirty-two, 80 ohms. With 200-volt lamps the resistances are double of these, and the currents are therefore halved.

88. **Regulation by Shunt Resistances.**—The ordinary way of using a resistance is to put it in series with the apparatus to be protected. The whole current then passes first through the

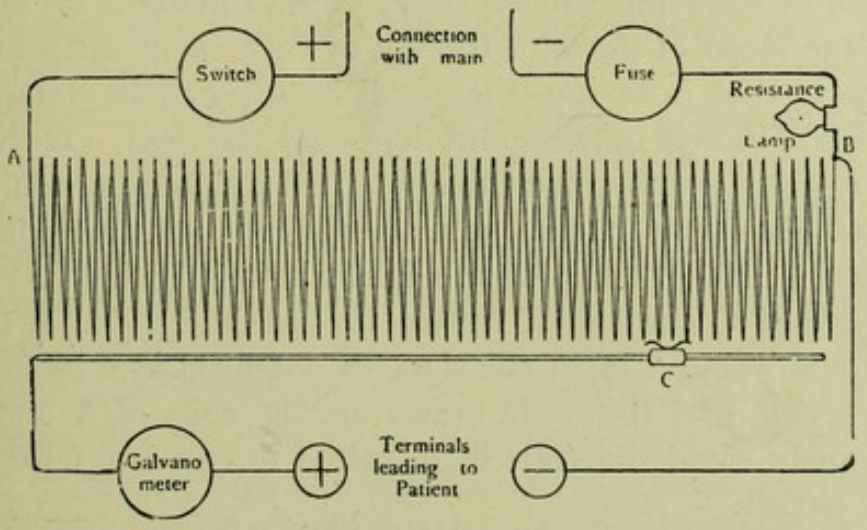


FIG. 84.—PLAN OF RESISTANCE IN SHUNT TO A PATIENT.

resistance and then through the apparatus regulated, and for many purposes a simple resistance in series gives all the regulation that is wanted. But another way of using resistances is to have them as a shunt or bridge to the piece of apparatus, the current dividing and passing in part by one channel and part by the other. This is known to engineers as the " potentiometer " method of regulation. When two circuits are arranged in this way in parallel, either of them is said to be " in shunt " to the other, or " shunted by " the other. Arrangements of resistances in shunt to apparatus are often useful, or two resistances may be used in series with each other, the patient (or the piece of apparatus) being arranged as a circuit in shunt to one of them, and Fig. 84 shows such a combination of shunt and series

resistances. The current from the main passes from the positive pole of the supply through a switch to A. From A to B is a resistance of wire, and B is a lamp which the current traverses to reach the negative pole, after passing through a fuse. Thus there is formed a closed circuit through the two resistances of the wire coil and of the lamp, with a fall or slope of potential between A and B, and a further fall through the lamp at B, the total fall being from 100 volts to zero on a 100-volt circuit. The circuit for the patient, or instrument, is arranged in a shunt to the wire resistance, and the voltage available in the patient's circuit will be varied by moving the traveller C along its metal slide. Let us suppose that the coils depicted are 450 in number, and that their resistance is nine times as great as that of the lamp B, then assuming our pressure at the main to be 100 volts, the drop of volts in the lamp will be 10 volts, and in the coils 90 volts. With 450 loops in the wire the fall of volts is one-fifth of a volt per loop—that is to say, there will be a potential difference of one-fifth of a volt between any loop and the next. If the loops were 4,500 in number then the potential differences would be as one volt for every 50 coils, and so on. The potential difference between C and B through the shunt circuit would increase as the traveller C was moved further towards the A end of the coil, because it would " tap " the slope of potential at a higher level, so to speak, and the more numerous the coils of A and B the more finely could the volts be adjusted to suit any needs of the shunt circuit.

With certain structural variations, chiefly in the number of the windings and the thickness of the wire, this method will suit all the cases which require a low pressure to be obtained from the electric light mains. The lamp acts as a safety resistance, and determines the maximum current which can pass through the apparatus. A certain latitude is afforded by the use of lamps of various candle-power for that portion of the resistance. When the current is to be applied to the lighting of a small surgical lamp which requires, say, an ampère, the safety lamp must be of such a character as to permit that amount of current to pass it. When a cautery is to be heated no lamp is arranged in series with the wire, and the various parts must be on a much larger scale, because they may have to waste energy at the rate of two horse-power or more when in use, and the current of five, ten, or twenty ampères which a cautery requires has considerable

heating effect upon the wires which lead to the cautery, as well as upon the cautery burner itself. The whole apparatus, therefore, becomes heavier and more expensive to make.

The applications of direct current from the mains to the commoner requirements of medical practice can be fully met by a set of resistances arranged to give slopes of potential, with arrangements for leading off at different points for the circuit in which the patient or the apparatus is arranged.

In shunt circuit regulation energy is continuously wasted, because a steady flow of current along one of the two conducting paths is necessary in order that the flow along this path, which may be called the regulating circuit, shall provide the gradual fall or slope of potential which is to be tapped for the other or utilization circuit.

It might be thought that regulation of current in the ordinary way by resistance in series with the patient would be sufficient for general medical purposes.

For instance, if it were wished to apply a current of 5 or 10 milliampères (0·005 or 0·01 ampère) to a patient from a 100-volt main this could be managed by a cheap graphite resistance of 20,000 ohms, reduced gradually to 10,000, but the effect upon the patient would be more disagreeable than that which he would experience with the same current from a source of electricity at a lower potential. If the resistance of the skin is high, as is frequently the case, it will be subjected to a needlessly high electromotive force unless extra care is expended in reducing the skin resistance by a preliminary soaking or thorough moistening of the skin, and on this account treatment of the kind indicated from the electric light main through a resistance in series is apt to be unpleasant. On the shunt circuit this is not the case, for the operator can commence the test or the treatment with a low electromotive force, which can be gradually raised as high as may be needed, so that the abrupt application of a high voltage to a badly conducting skin surface is avoided.

89. **Shunt Circuits for Heavy Currents.**—When large currents are required, the advantages of a shunt circuit over regulation by resistances in series becomes even more evident for certain applications. In the case of a galvano-cautery requiring ten ampères to heat it, the current from the 200-volt main could be choked down to the required magnitude by a resistance of twenty ohms in series with the cautery instrument, but to use it

in this way would be positively dangerous. Ten ampères of current is quite sufficient to maintain an electric arc across a small air-gap, and it might easily happen that on breaking the circuit in the usual way with a key in the handle of the cautery instrument an arc would be established at that point which would instantly destroy the handle. Or, again, if from any cause the platinum of the cautery should break or fuse during its use, the establishment of an arc, with an accompaniment of drops of fused platinum and copper in contact with a patient, might have serious consequences.

The risk of such an accident can only be avoided by having two parallel circuits from the positive to the negative main, one to carry the cautery and the other to act as the shunt circuit in case of accidental fusing or fracture of the cautery wire. No arc need then be feared, the only drawback being that the apparatus expends much energy while it is in action, and special main wires and fuses are required to carry the current. As each branch may have to carry upwards of ten ampères when the cautery is at work, they must be constructed in a substantial manner to stand that magnitude of current.

So, again, in the case of Ruhmkorff coils worked from the mains. From a shunt circuit pressures of 20, 30, or 40 volts can be applied at the terminals of the coil, and the sparking at the contact-breaker is very much less than it would be with the same current cut down by a resistance in simple series. In the latter case the spark is almost explosive in its violence, so much so that only the most rapid breaks can be used to operate large coils direct upon the mains without shunt circuit regulation.

Shunt circuit instruments for use with heavy currents are made as a rule of a number of open coils of thick iron wire affixed to the back of a slate or marble slab with ample air spaces for ventilation, by which means the heat generated in the coils is dissipated. The coils are joined together in a series, and at intervals a connection is led off to a stud on the front of the switchboard, whence the current is taken to the appropriate binding screws through a moving crank arm, or else connections are made to one of a number of separate plug sockets for the different circuits of utilization (Fig. 85).

Thus in Fig. 85 the wire coils of the shunt circuit are composed of sixteen lengths of a spirally-coiled wire. If the potential difference between the positive and negative wires of the source

is 100 volts, the difference of potential existing between the two ends of each section will be one-sixteenth part of the total, and between the beginning and end of a double section one-eighth of the total, or, in the case under observation, 12½ volts, and thus the row of studs numbered from 1 to 8, which are connected to points on the resistance, provide places from which current can be drawn at any one of a series of intermediate voltages. When the crank arm stands on the stud numbered 1 the difference of potential between the terminals B, B will be one-sixteenth of

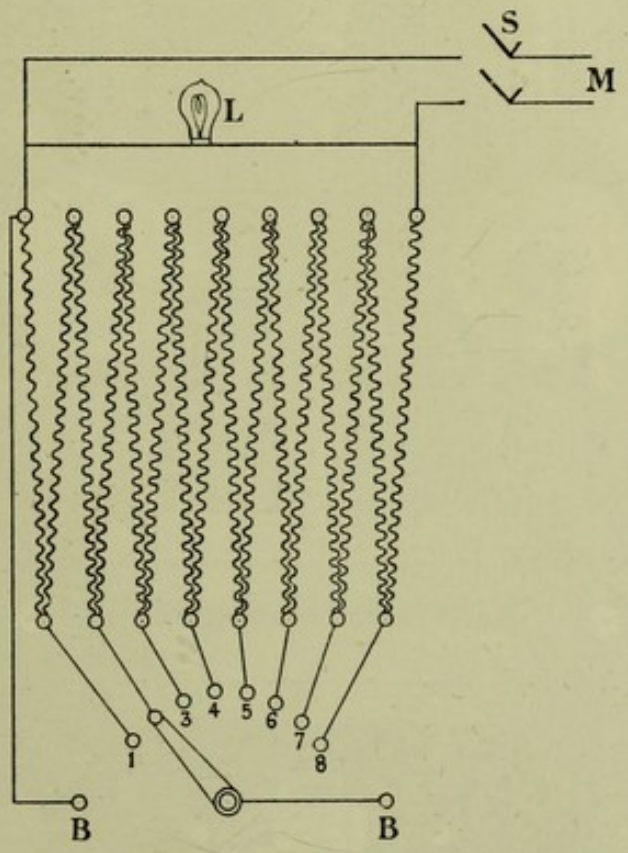


FIG. 85.—PLAN OF SHUNT CIRCUIT RESISTANCE.

M, Mains; S, switch; L, pilot-lamp; B, B, terminals.

the total pressure supplied by the main, or a little over 6 volts, and when it stands at the second stud, as shown in the figure, the difference of potential between B and B will be 18 volts.

A lamp is often fitted to the switch-board to indicate that the current is on through the coils. This is useful in order to prevent unnecessary waste. The coils of wire form a closed circuit, and according to the number, length, and thickness of the iron wire coils the flow of current through them may be ten or twenty ampères or more. A voltmeter and ampèremeter and a

safety fuse are added, and in some cases an adjustable resistance for further regulation in the utilization circuits is used to make the switchboard complete.

Fig. 86 shows the general appearance of a shunt switchboard

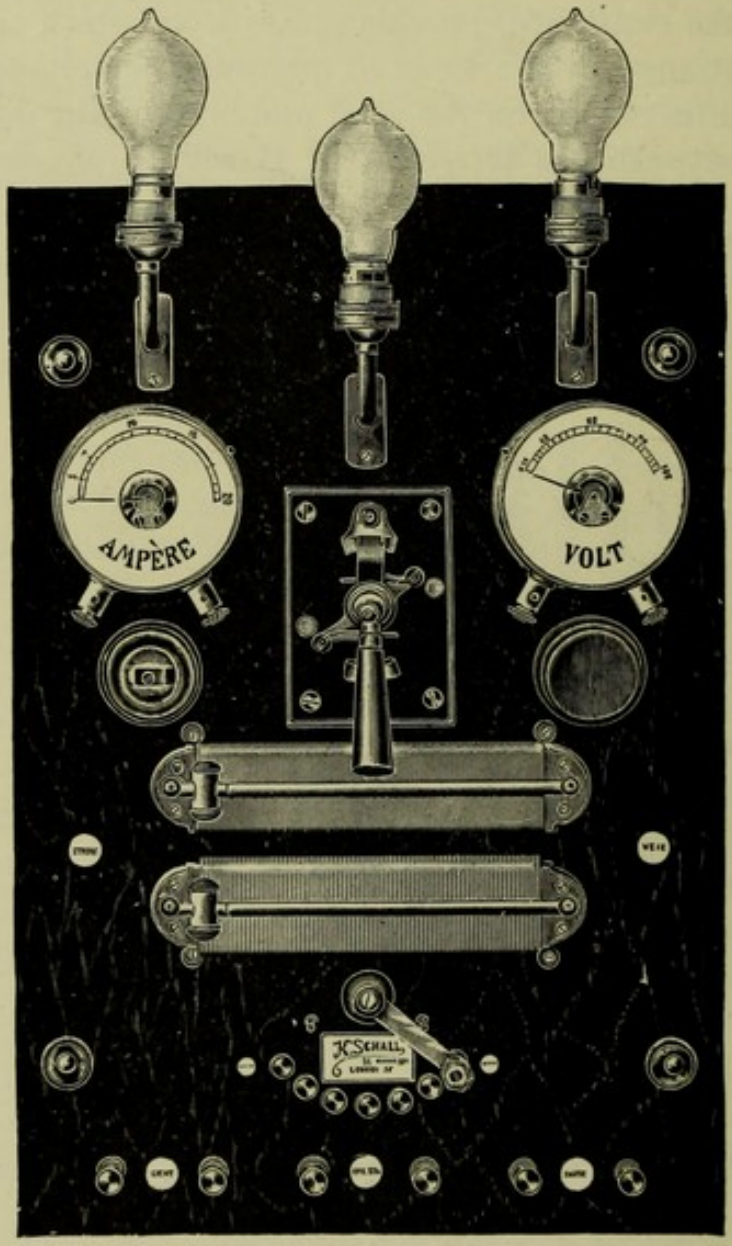


FIG. 86.—SHUNT CIRCUIT RESISTANCE FOR LARGE CURRENTS.

with two small adjustable series resistances added. One of these is in the lamp circuit, the other is for a cautery circuit.

As long as the switch is closed a large current passes through the shunt circuit and has to be paid for, although only a portion is being taken from the utilization circuit. This is a considerable waste, and if large quantities of electricity were required such rheostats would be extravagant. If the shunt carries 15 ampères

and is left connected with the main for one hour, the consumption of current with a 100-volt supply is one and a half units, and it is twice as much with a 200-volt supply. The price of the unit being 6d., the cost for using the apparatus for one hour on a 100-volt supply will be 9d. As the resistance does not deteriorate, and requires no time for cleaning and recharging, the

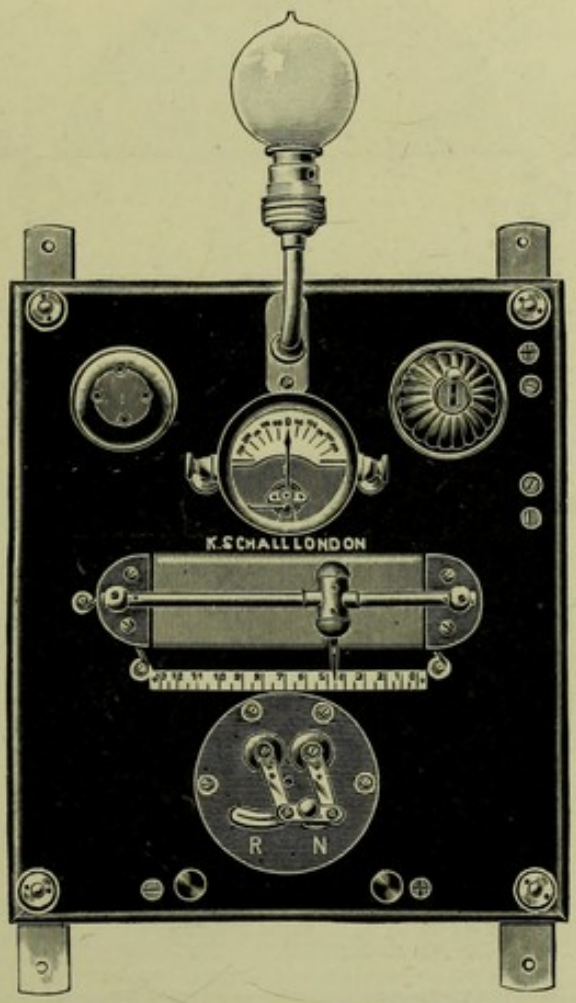


FIG. 87.—RESISTANCE INSTRUMENT WITH ADJUSTING SLIDE AND COMMUTATOR.

saving of cost of renewals and the saving of time may be set off against this expense.

It will be seen in the succeeding sections that series resistances suffice for some purposes, although for others a regulation by shunt resistances is absolutely necessary.

90. **D. C. Applications to Patients.**—A simple switchboard on the shunt resistance principle is shown in Fig. 87. It can be used for direct applications of "galvanic" current to patients, and is provided with a milliampèremeter.

An illustration of a more ambitious switchboard is shown in

Fig. 88, which represents a fitting for a wall, with resistance-lamps, wire resistance for shunt regulation, milliampèremeter, induction coil, commutator, and box for cords and electrodes. The three lamps form part of the shunt resistance, and are useful

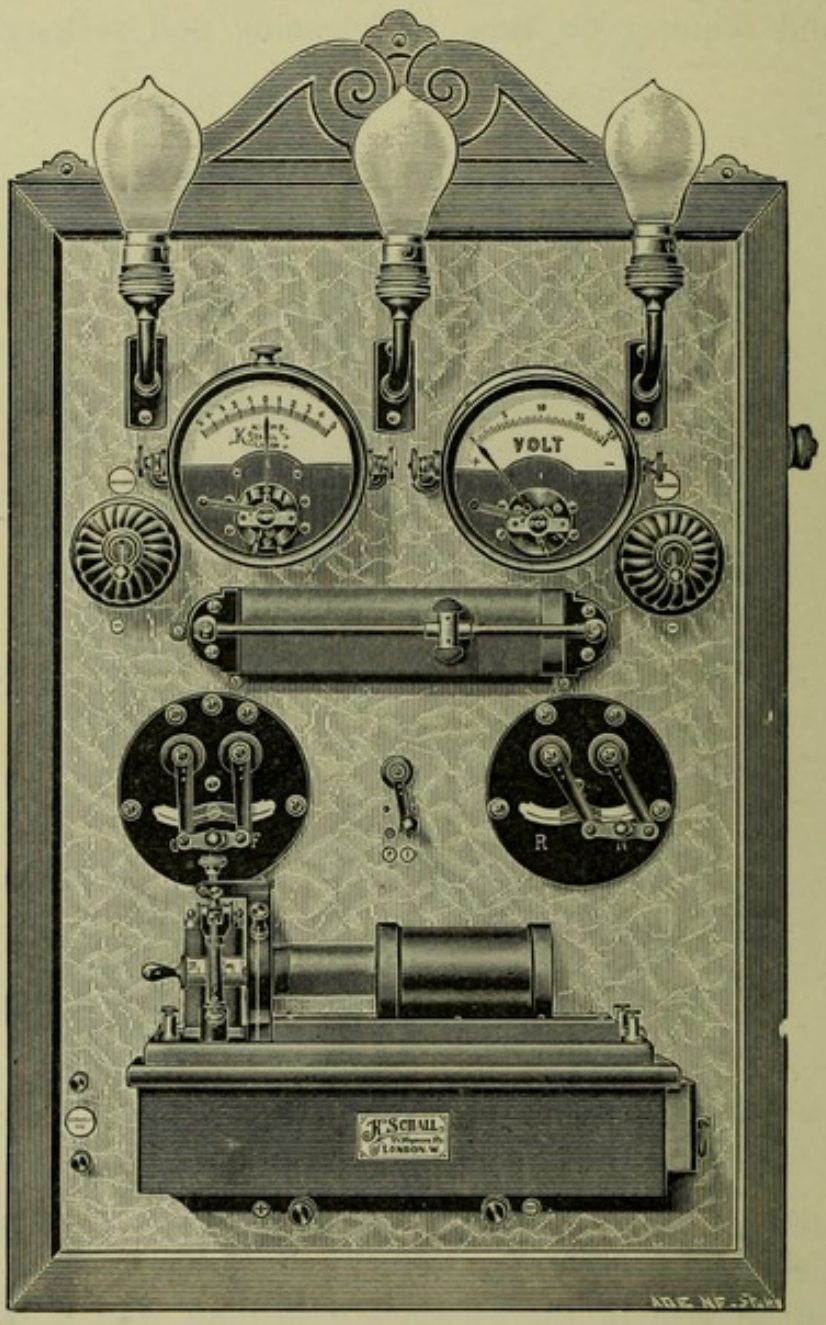


Fig. 88.—Complete Fitting for Utilization of Direct Current Mains for Medical Uses.

in the induction-coil circuit. Similar fittings are also put together on tables, and in desk form for convenience of transportation to and from the bedside.

For the design of these pieces of apparatus the profession is

largely indebted to the late Dr. Milne Murray, who originally planned them for the Edinburgh Royal Infirmary.

In the past the induction coils supplied on these switchboards have not been very satisfactory. They have interruptors moved by a separate electro-magnet for the sake of providing a sliding core, and we have seen that such coils give slow and irregular shocks (see Fig. 33), and should be condemned. It would be better to use a more rapid interruptor worked by a slender fixed core, and to regulate the " primary current " by a resistance. Or possibly it would be better to abolish the coil altogether, and replace it by a mechanical interrupter of the kind described in § 63.

Another point requiring attention with these switchboards is the protection of the milliampèremeter. This must be guarded

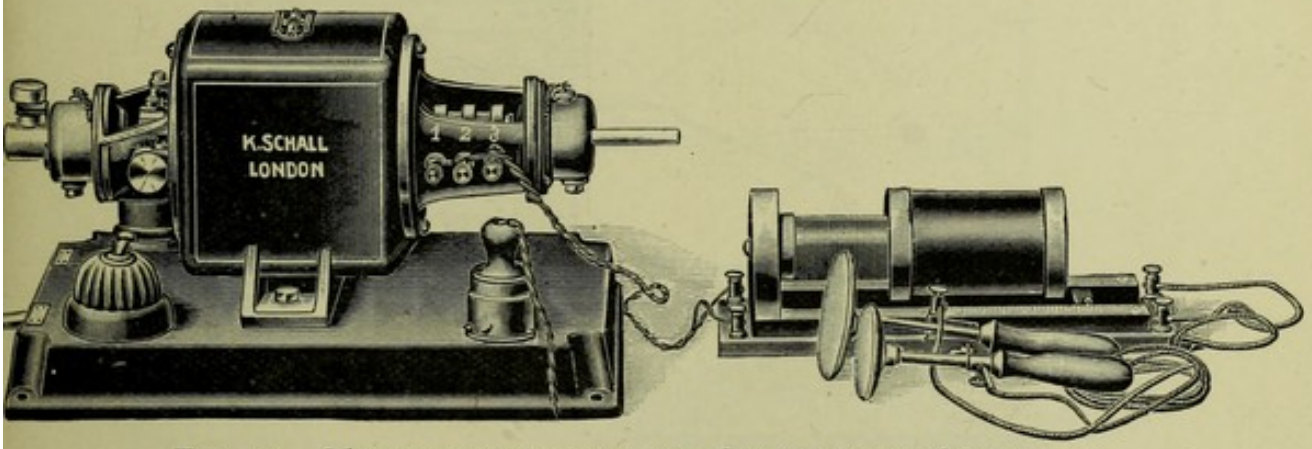


FIG. 89.—MOTOR-TRANSFORMER FOR SINGLE-PHASE SINUSOIDAL CURRENTS.

against short circuits, as these would be very likely to overheat and destroy the windings of the galvanometer coils. Dr. Milne Murray has attempted to obviate this by providing the milliampèremeter with a short circuiting key, which is to be removed only during actual measurements of current.

91. **D. C. Sinusoidal Current.**—A direct current motor may be made to yield alternating current by tapping the armature windings at two diametrically opposite points, and leading out connections from these points to a pair of rings insulated from each other upon the shaft of the machine. A pair of brushes in a brush-holder collect the current from the rings, and deliver it into an external circuit as a sinusoidal current. Its voltage can then be transformed up or down to suit the applications for which it may be required.

The transformer, if carefully made, serves also to protect the alternating-current circuit from any leakage into it from the direct current side of the machine. As sinusoidal current is especially used in conjunction with electric bath methods, where leakages to earth are probable, this precaution is an important one. Leakages of current to earth through a patient immersed or partly immersed in water have proved fatal, as a patient under these conditions is deprived of the protection usually

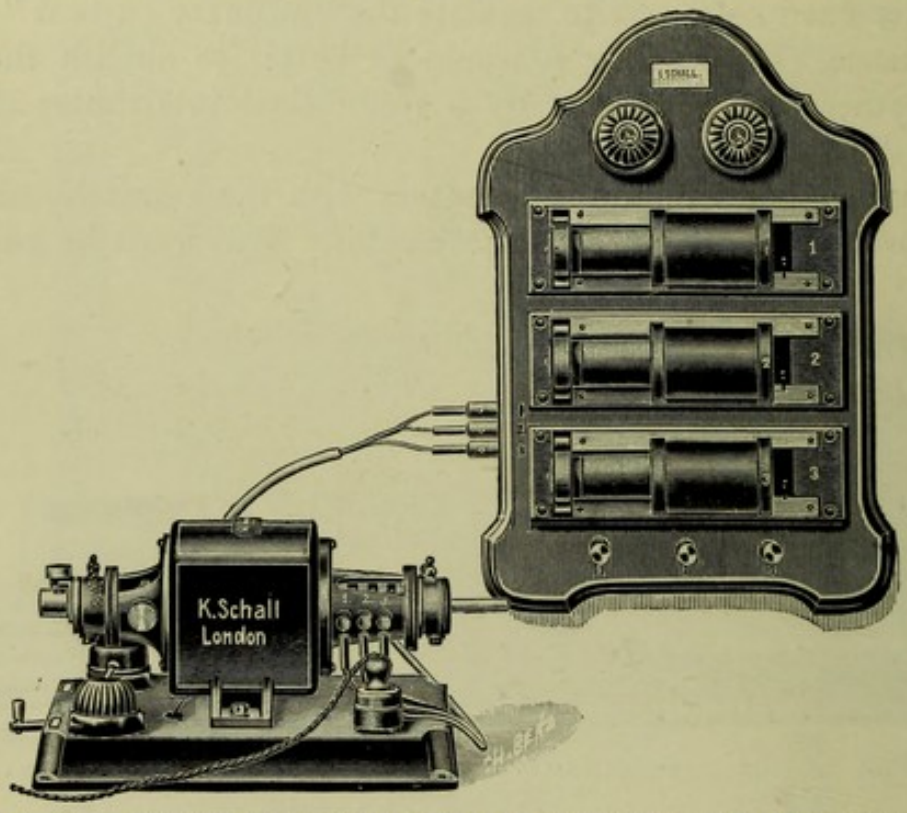


FIG. 90.—MOTOR GENERATOR FITTED FOR GIVING THREE-PHASE CURRENTS, WITH TRIPLE TRANSFORMER.

afforded him by the resistance of his dry skin and his clothing.

The use of D.C. mains to generate sinusoidal current is not limited to the applications of the latter to patients. For some medical applications of electricity, especially for lamps and galvano-cauteries, the object desired is best obtained by using a motor-transformer to convert the direct into alternating current for the sake of the facility with which the latter can be adjusted for these purposes by means of a transformer.

92. **Polyphase Currents.**—A few words on the subject of three-phase currents may be useful, because it is possible that their employment for medical purposes may become extended in the future.

A simple alternating current has been described in § 52, and its properties are fairly familiar to those medical men who are at all interested in electrical matters.

It may be spoken of as a single-phase current to distinguish it from two-phase and three-phase currents. Polyphase currents have recently been proposed for medical uses, and in this country Dr. George Herschell* has written on the subject, and has described a method of generating and regulating three-phase currents for medical uses.

Fig. 90 shows an apparatus designed for the purpose of generating three-phase currents. It consists of a D.C. motor with three slip-rings on its axle. The three-phase current is collected by brushes on these slip-rings, and carried by three conductors to the primaries of three transformers coupled

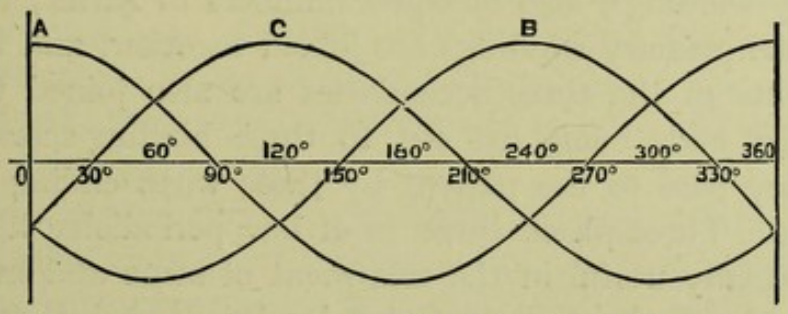


FIG. 91.—DIAGRAM OF THREE-PHASE CURRENTS.

together for the simultaneous regulation of the currents in the three circuits.

A dynamo for generating three-phase currents is designed with three separate sets of windings in the armature, these separate sets of windings being so spaced out as to come into inductive operation in regular succession; there will then be three separate circuits of equal voltage, which may be collected by brushes rubbing on three pairs of slip-rings, or they may be connected up by grouping in the case of three-phase by having one end of each led to a common junction inside the machine, and the three other ends led to three slip-rings, and so to three live wires. A D.C. motor generator may be used in exactly the same way to give three phase currents.

Fig. 91 is a diagram to represent the nature of a three-phase current as compared with simple alternating current. A, C, B mark the tops of a wave of each of the three phases, the numbers indicate degrees of angular distance to express the intervals in

* 'Polyphase Currents in Electrotherapy' (London: Glaisher, 1903).

the course of a revolution of the generator at which each coil comes into operation.

The diagram, though commonly used to represent three-phase currents, must not be thought to imply that all the changes indicated take place in one circuit. Three circuits are required, indeed for some purposes it would be better to represent three-phase currents by three simple sine curves on three separate horizontal lines, connected by vertical lines to indicate the time-relationships of the rise and fall of E.M.F. in each conductor. If one imagines this to be done with the diagram, it would be seen that whenever one of the circuits is occupied by a positive wave-crest the other two are negative to it.

A three-phase transformer for medical use has three iron cores wound with equal turns of wire for the primary coils, and three secondary windings, also of equal numbers of turns; the three ends of the primary windings are joined together, and the commencements of the three secondaries are also joined together, their other ends being led out to three binding-screws, from which they pass to the patient by three wires ending in three electrodes. Three-phase currents of low periodicity have been found specially useful in the treatment of some abdominal disorders, and are also recommended by Dr. Herschell for use in the electric bath.

93. **To Charge Accumulators.**—It is often convenient to use the direct current to charge accumulators, which can then be detached from the mains and used independently, as, for example, for providing a portable apparatus to take to a patient's house. Although a desire for absolute uniformity of practice, or the idea of saving one's self trouble, might make one wish to use current from the mains only, without any accumulators, the advantages on a practical side all lie in a combination of the two methods; that is to say, in the use of accumulators for some purposes, and in direct applications of the current from the mains in others. Thus the simplest way for lamp and cautery work is to charge a portable accumulator from the mains, and then to use the accumulator for the lamps or cautery. Many surgeons only need current for these purposes, and with a portable accumulator and a lamp-resistance for recharging they can be fully equipped at a small outlay.

To charge an accumulator from the direct current mains the battery must be connected so that the current which goes

through it must also go through a resistance, the favourite form for this being an incandescent lamp. In the case of a lamp supplied from a flexible cord the conditions would be met by cutting one part of the double wire, and untwisting the cut ends for a few inches, so as to give sufficient length for connection to the two ends of the battery. As one of the severed ends is positive and the other is negative there will be a right and a wrong way of connecting up. In the former the direction of the current from the main will be opposed to that of the battery, the lamp will burn more dimly, and the battery will receive a charge. In the latter it will not receive a charge, but, on the contrary, it will discharge, reinforcing the current of the main, and the lamp in the circuit will burn too brightly. The effect on the lamp is the simplest guide to the right way of coupling up the battery, and when once determined, the ends may be marked in some way for future guidance. Another way of testing the polarity of the ends of wire is to use moistened litmus-paper ; the paper will be stained red where it touches the positive pole, and blue where it touches the negative (§ 67).

Ready-made appliances for charging through a lamp can be bought at the instrument-makers. Usually they consist of a board carrying one or more lamps in sockets, with a pair of charging terminals, and a flexible wire with plug for attachment to wall-socket or lamp-socket, as may be desired. A form of lamp with binding-screws (Fig. 92) is also made for the purpose ; the path of the current through such a fitting may be understood readily from Fig. 93. It is as well to bear in mind that with the ordinary two-prong wall-plug, and with the lamp-socket with bayonet-catch, there are two possible positions of insertion of the lamp or plug, and therefore the binding-screw, which is positive for one way, will be negative for the other. With concentric wall-plugs and screw-socket lamps the polarity is always the same.

The charging current through a 16 candle-power lamp on a 100-volt circuit is about 0·6 ampère, on a 200-volt circuit about 0·3 ampère, on a 240-volt circuit about 0·25 ampère. The current can be increased by the use of a number of lamps arranged in parallel to one another, or by the use of lamps of higher candle-power. For purposes of rough calculation a 32 candle-power lamp carries twice the current of a 16 candle-power lamp, and so on in proportion.

Dr. E. E. Maddox* has devised a convenient form of lamp-resistance, the "Stella" lamp,† which is composed of a circular brass band, in which a number of lamp-holders are fixed radially, four of them being in parallel, while one, and also a pair of binding-screws, are placed in series with these four. Any lamp placed in one of the four holders contributes its current to the efferent cord which is attached to the binding-screws, or to the fifth lamp-holder.

When the charging of the cells from the mains is to be done frequently, it may be worth while to have the charging terminals connected to one of the house lamps which is in regular use,

FIG. 92.—LAMP-RESISTANCE WITH SOCKET FITTING FOR CHARGING SECONDARY CELLS FROM THE MAINS.

in order not to waste energy. As the electromotive force of the cells which are under charge is opposed to that of the charging circuit, the lamp will be dimmed to a certain extent by the counter-electromotive force of the cells; this can be met by using a lamp of lower voltage. Thus on a 100-volt circuit, a 90-volt lamp in series with an accumulator of four cells (8 volts) would be brought to full incandescence, and would give a good light while the accumulator was being charged. On 200-volt circuits the light is not much reduced by the interposition of a 4-cell accumulator, and a special lamp is therefore hardly needed.

* *Trans. Ophth. Soc.*, vol. xxiii., December, 1902.

† The Stella lamp is made by Miss Long, 85, Crouch Hill, N.

94. **D.C. Galvano-cautery Work.**—There are many ways of applying the D.C. mains to galvano-cauteries.

The simplest by far is to charge an accumulator, and to use

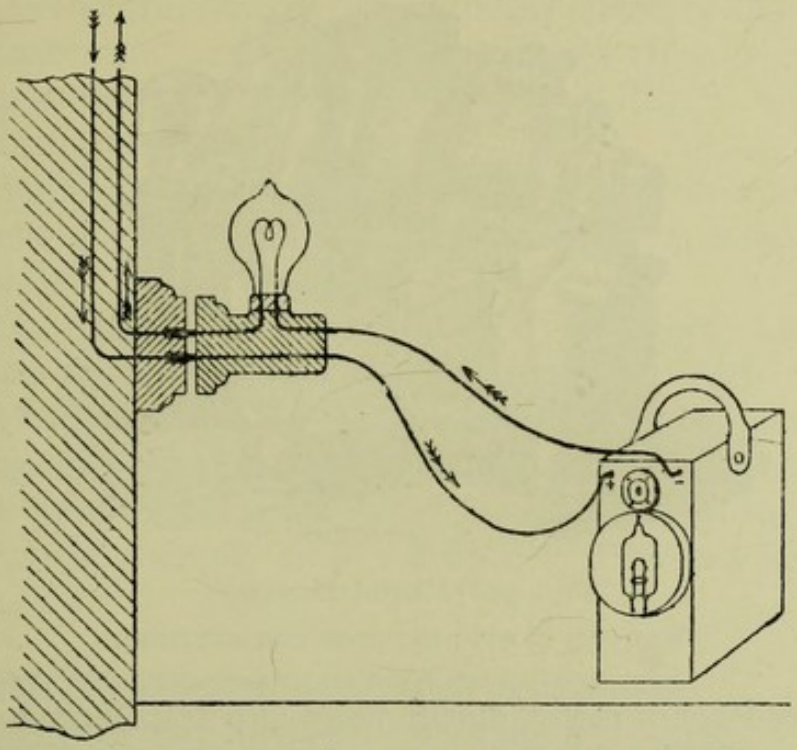


FIG. 93.—CHARGING AN ACCUMULATOR FROM THE ELECTRIC LIGHT MAINS.

that for heating the cautery. This has the advantages of portability and of cheapness.

Another plan of procedure is to convert the high-pressure

FIG. 94.—LAMP RESISTANCE BOARD FOR CHARGING ACCUMULATORS.

current of the mains into a low-pressure current by one of the following methods :

First, by the use of a motor dynamo fitted with two distinct windings on the armature, the one to receive a small D.C. current at 100 or 200 volts, and the other to give out a large current,

also D.C., at 10 volts. The latter can then be regulated to suit either cautery or lamp instruments by means of a small and inexpensive series resistance.

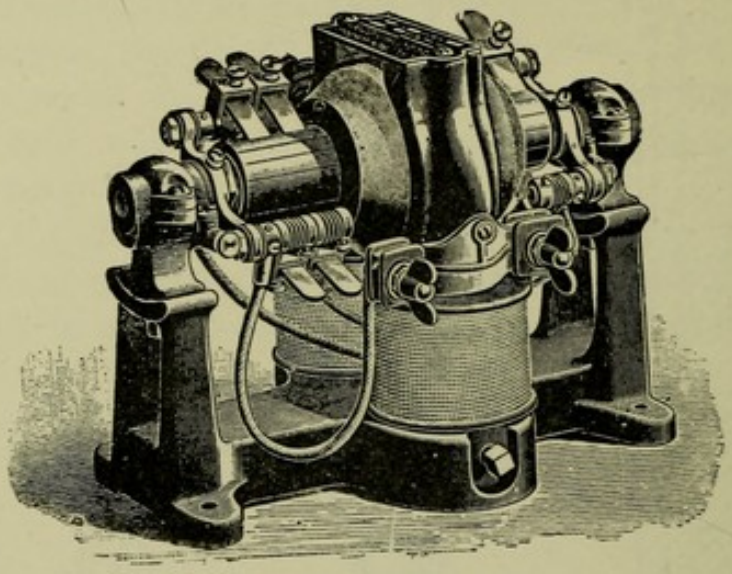


FIG. 95.—MOTOR DYNAMO.
Two sets of windings upon one armature.

Another form of motor dynamo or motor transformer converts the direct into alternating current, and this is regulated to suit

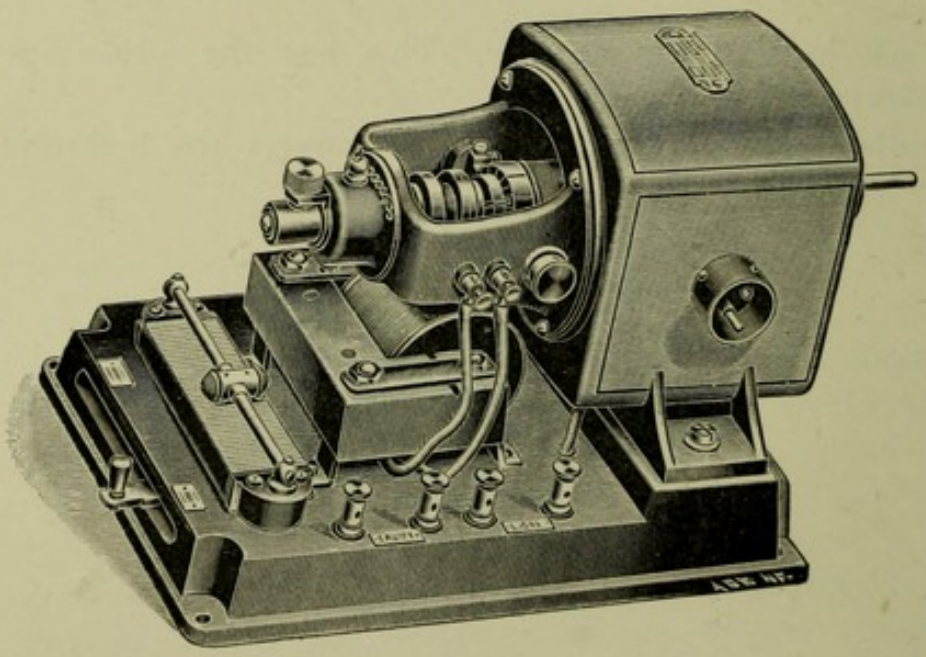


FIG. 96.—MOTOR TRANSFORMER FOR LAMPS AND CAUTERIES.

the requirements of cautery or lamp instruments by a transformer (Fig. 96).

A third apparatus in common use is fitted with a platinum

interrupter, and resembles an induction coil, but its function is the opposite of that of an ordinary induction coil, because it increases the current at the expense of the electromotive force. It is an ingeniously contrived apparatus, it uses very little current, and is fairly trustworthy in operation. A cheaper apparatus based upon the same principle of transforming an interrupted current is illustrated in Fig. 98.

The shunt-circuit apparatus with heavy wires described in § 89 can also be used for galvano-cautery work, but is inferior to the methods already described.

95. **D.C. Small Lamps.**—From what has been said in the section on charging accumulators (§ 93) it will be recognised that the use of a small portable accumulator presents distinct advantages for use with incandescent-lamp instruments. They may also be operated quite easily from the mains by reducing the current in a simple series resistance. This may be entirely

FIG. 97.—RHEOSTAT FOR SMALL LAMP.

of wire, or partly of wire with an ordinary incandescent lamp included in the circuit for purposes of economy. The lamp is a cheap form of resistance, and offers a convenient way of dissipating the energy which has to be wasted. In cases where its light would be inconvenient a lamp of red or blue glass can be substituted, or else a resistance composed wholly of wire may be used. The lamp chosen must allow the passage of a current sufficiently large to bring the smaller surgical lamp to incandescence. By reason of their relatively thick filaments some of these small lamps may need a larger current than a full-sized 16 or 32 candle-power lamp. The use of a series resistance may involve risks of leakage currents to earth, with shocks to the operator holding the lamp, if he should be standing on a damp floor, or should touch metallic objects connected to earth.

Fig. 97 illustrates a rheostat described by Mr. Crawford Renton in the *Lancet* for June 24, 1905, for use with the cysto-

scope. The rheostat works upon the ordinary electric light circuits, and the current is reduced through a 50 candle-power lamp. Mr. Renton states that the cost of the rheostat is only 30s.,* and that it is easily carried in an ordinary small operating-bag. Surgical lamps may also be lighted by a motor transformer as indicated in the preceding section.

Fig. 98 shows an apparatus of a simple kind for direct current circuits of 200 volts and upwards. It consists of an electrolytic interrupter with a transformer for regulating the interrupted current produced. It is designed for the heating of cautery burners and small lamps. The very largest burners are within its capacity, and good heat regulation can be obtained with any size. The apparatus is always ready for work without any preparation or charging. If left idle there is no deterioration.

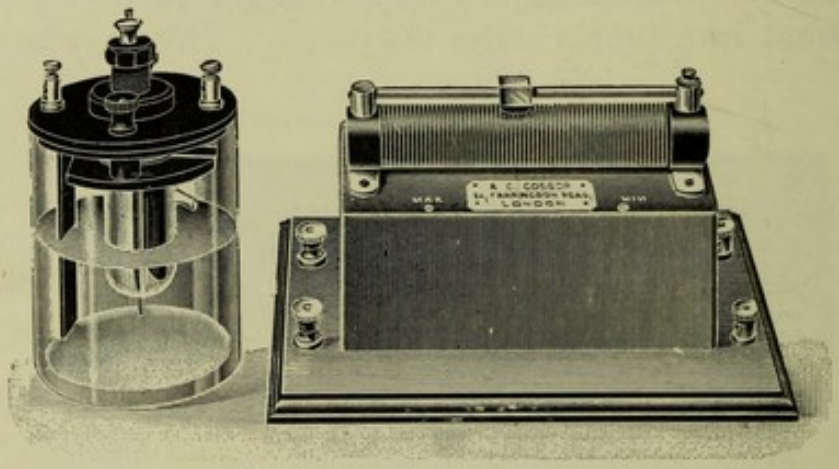


Fig. 98.—Electrolytic Interrupter and Transformer for Lamps and Cauteries.

It may be connected to any lamp-holder, as the current taken from the main is never more than 2 ampères when heavy burners are in use. The usual current consumption is from 0·5 to 1 ampère. Upon alternate current circuits the electrolytic interrupter may be cut out and the transformer used alone.

96. **Alternating Current—Transformers.**—The general principles of the transformer have been mentioned in § 53, and, as might be expected, it is often of use in medical work.

The commonest type of transformer for medical use is a step-down apparatus, or one which is used to convert a small alternating current at the pressure of the electric lighting mains into a larger current at two or four volts for cauteries, or at eight

* Mr. J. Trotter, 40, Jordan Street, Glasgow.

or ten volts for small incandescent lamps, or to generate sinusoidal current at a low pressure for use in the electric bath. Transformers are also used for the generation of very high

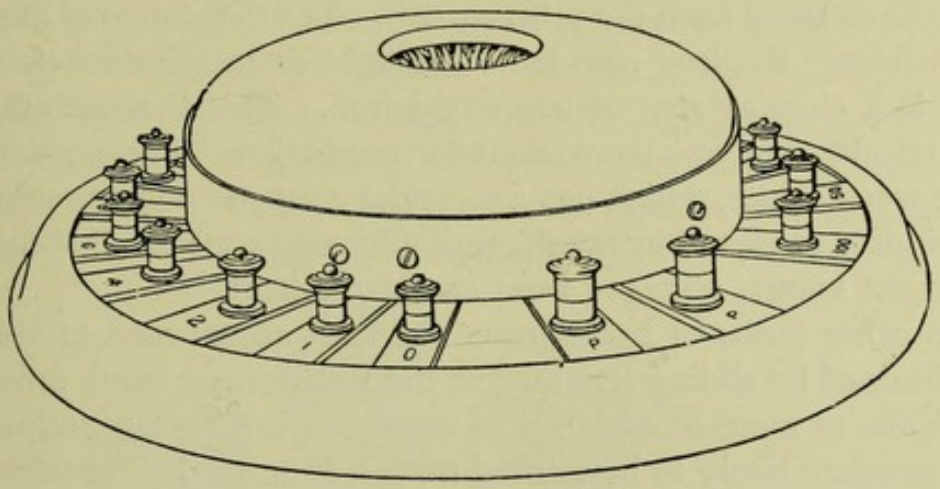


FIG. 99.—TRANSFORMER GRADUATED IN VOLTS.

pressures of many thousand volts for X-ray work, or for working high-frequency apparatus.

The first transformer specially designed for medical use was

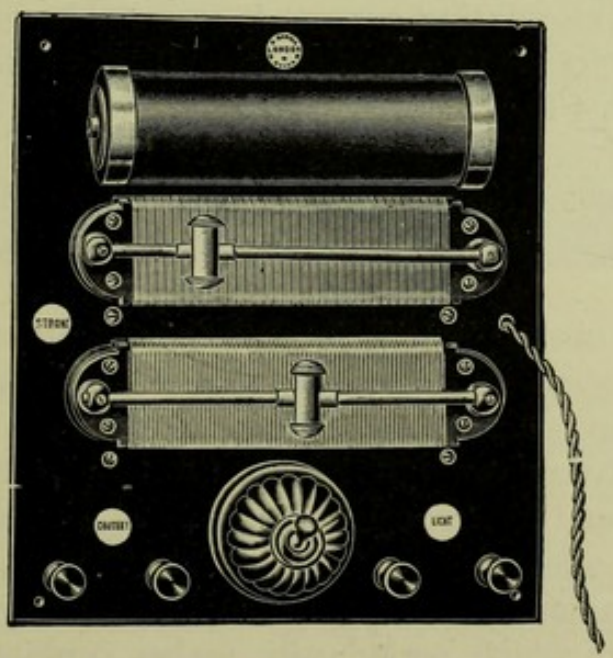


FIG. 100.—TRANSFORMER, WITH TWO SLIDING RESISTANCES, FOR CAUTERY INSTRUMENTS AND FOR SMALL LAMPS.

Woakes' transformer, which dates from 1891. It had several secondary coils wound upon the same bobbin—one for cautery to give about four volts, and wound with thick wire to carry a

heavy current without heating; one for small lamps, and one for therapeutic purposes. Each secondary had its own terminals, and all were excited by one primary coil. Regulation was effected by a sledge-coil arrangement bringing the secondary coils to or away from the primary coil. In other forms of medical transformer the iron core is not straight as in Woakes' pattern, but is a circular ring of laminated iron. This is more efficient electrically, but less convenient for regulation. Fig. 99 shows a ring transformer, which has a secondary tapped and brought out to binding screws at intervals, thus affording a means of obtaining different known voltages from one instrument.

In other forms of transformer the final adjustment of voltage is obtained by sliding resistances, the transformer being provided with one or more secondaries so wound as to give approximately the pressure likely to be wanted from it (Fig. 100). Transformers for high pressures or step-up transformers are used in medical work for the production of X rays, for certain forms of lamps used in treatment, and for high-frequency currents. These transformers will be described in detail in the succeeding chapter.

97. **A.C. Conversion into Direct Current.**—For some medical purposes the alternating current is unsuitable, and a means of obtaining direct current from the alternating supply may be much desired. The following plans have been proposed for this purpose:

1. An alternating-current motor may be used to drive a D.C. dynamo. These may be coupled by a belt, or may be built upon one shaft.

In either case there is a conversion of electrical into mechanical energy, and a reconversion of mechanical energy into electrical again. The method gives wide choice on the generating side, as the dynamo may be chosen to give any desired electromotive force and current up to the limits of the energy expended on the motor side.

2. A mechanical rectifier may be used, and by this is meant an instrument which periodically makes contacts, closing the circuit at such intervals of time as to transmit the impulses passing in one direction, while arresting or diverting those impulses which would tend to pass in the opposite direction. A rectifier, therefore, does not give a smooth flow of direct current, but a series of distinct impulses which all pass in the

same direction. This may be quite as useful as a steady current for some purposes, but less so for others.

There are several rectifiers in use among medical men, though none have come into very extensive use, because of the greater convenience of the chemical or electrolytic rectifier, to be described immediately. Batten's rectifier consists of a short steel rod magnetically polarized, and moving on a pivot between the poles of an electromagnet fed by an alternating current. It is attracted by each pole in turn as the direction of the current changes, and in its excursions it makes contact with each of two

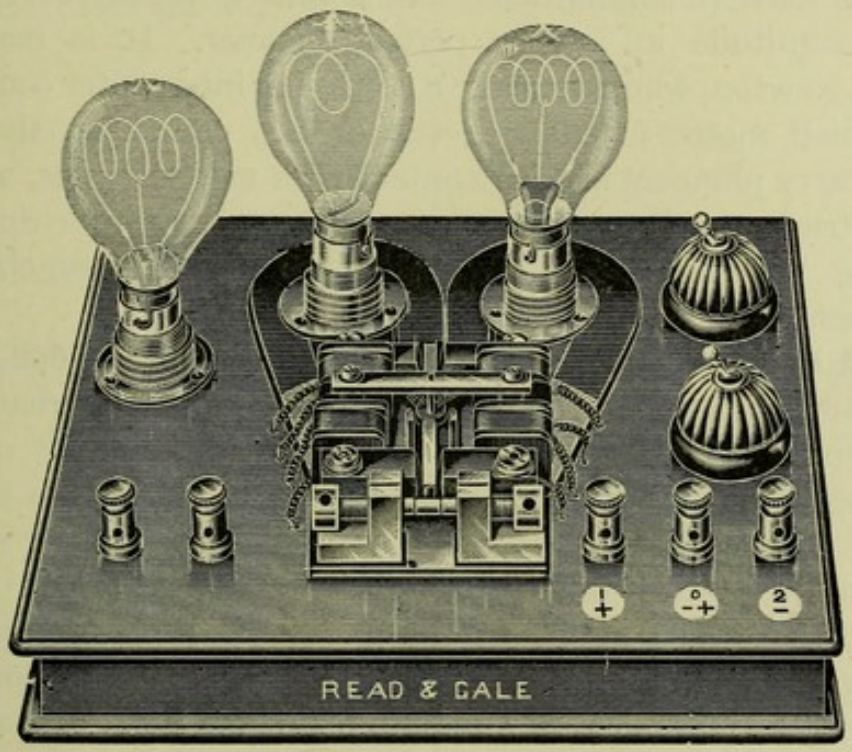


FIG. 101.—BATTEN'S RECTIFIER.

studs, and so closes the circuit of utilization. It is so arranged as to permit of the employment of both semi-periods of the alternating current, so that, for example, two sets of accumulators can be charged simultaneously.

A very ingenious detail of Dr. Batten's rectifier is the use of a tinfoil condenser in the magnetizing circuit, and of a self-induction coil in the rectifier circuit. This device reduces the sparking at the contacts, and is valuable on that account. Another useful feature of the Batten rectifier is that the pressure of the mains can be reduced to any required value by a transformer before rectification with a proportionate increase in the current. This is economical, and often useful otherwise.

An apparatus of the same type on a larger scale is made by Messrs. Siemens Brothers for charging accumulators, or as a synchronous interrupter for large induction coils. In the latter case the contacts are arranged to take place near the tops of the alternating current waves, and the contact surfaces of platinum are massive to carry large currents.

Other types of rectifier operate by means of a revolving commutator fixed on the axle of a synchronous motor. The rectifier of Dr. Reginald Morton is a machine of this type, with a self-starting mechanism for bringing the motor into synchronism. It has a massive commutator, and is able to rectify currents of large magnitude in a very perfect manner. It is made by Messrs. Newton, who also make a rectifying interrupter consisting of a small motor fitted with one or two cranks on the axle. These carry plungers making contact with mercury cups, so that the instrument serves at once as rectifier and as interrupter for working Ruhmkorff coils. It starts easily into synchronous movement with a touch from the finger.'*

98. **A.C. Electrolytic Rectifiers—The Aluminium Cell.**—This is a most valuable contrivance for obtaining direct currents from the alternating mains. It is far more suitable for medical purposes than any mechanical rectifier, and it has no moving parts. Its value depends upon a peculiar behaviour of aluminium, by which it offers a very high resistance to the passage of a current when acting as the anode of an electrolytic cell, although as kathode it offers no such resistance. Accordingly an electrolytic cell having aluminium for one pole, and another metal or carbon for the other, will tend to arrest the passage of an alternating current through it in one direction, while readily permitting a flow in the other direction. This property of aluminium has been known for many years, having been discovered by Buff in 1856. Its practical application to alternating currents was suggested by Ducretet in 1876, and later by Graetz, Pollak, and others. Of late the aluminium cell has been extensively studied, and very much improved for practical purposes.

A simple aluminium cell can be made of a plate or rod of aluminium immersed in a jar of ammonium phosphate solution, with an iron plate for the other pole. With such a cell arranged in series with a resistance, as, for example, with a lamp-resistance

* *Archives of the Roentgen Ray*, April, 1902 (description and figure).

like those shown in § 93, the alternating mains can be used to charge an accumulator if the aluminium cell is so connected up that the direction of flow from iron to aluminium is towards the positive terminal of the accumulator, and a direct current ammeter in the circuit will give readings of the mean charging current.

As half the impulses are arrested by the cell, the readings will be half of those for which the candle-power of the lamp is rated (§ 88)—thus, with a 32 candle-power lamp on 100-volt mains the accumulator will be charged at the rate of about half an ampère, allowing 0·1 of an ampère for loss in the system. By using a

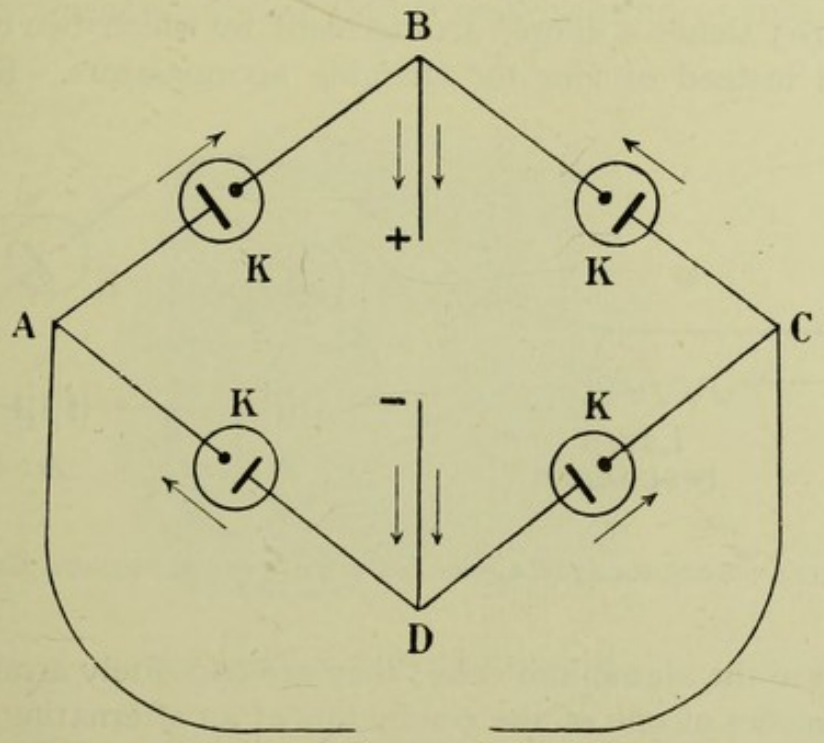


FIG. 102.—ARRANGEMENT OF ALUMINIUM CELLS IN NODON VALVE.

combination of four cells both phases of the current can be utilized in one circuit.

The disposition of cells shown in Fig. 102 is due to Graetz, and is an application of the principle of the Wheatstone's bridge (§ 44). Four cells are taken and arranged in a circuit, as shown at K, the direction from iron to aluminium being indicated by the arrows. The alternating current is applied at A and C. No current can pass in either direction, for it is opposed by one or other of the aluminium cells, but if B and D be connected a current will flow from B to D. When A is the positive pole the flow will be by A B, D C, and when the electromotive force is

reversed and B is positive, it will flow by C B, D A, always, therefore, from B to D through any circuit joining B and D. The system may be regarded as a Wheatstone's bridge circuit, in which the resistances automatically change with the changes of sign of the alternating electromotive force applied at A and C. The Nodon valve and Pollak's rectifier are arrangements of aluminium cells on this principle, and they may be used successfully not only for charging accumulators, but also for driving direct current motors, and for the operation of Ruhmkorff coils. The current given out by these forms of rectifier is not steadily sustained, but though pulsatory it is unidirectional, and for many practical applications it may be employed as direct current.

Fig. 103 shows a simple arrangement by which two cells can be used instead of four for charging accumulators. K K, as

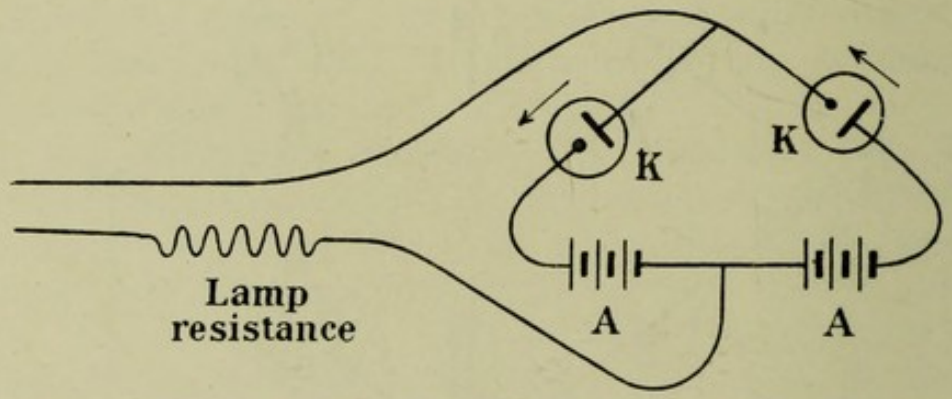


FIG. 103.—ACCUMULATOR CHARGING WITH TWO ALUMINIUM CELLS.

before, are the aluminium cells ; they are oppositely arranged on two branches of one of the conductors of an alternating circuit, the other conductor is joined through a resistance to the middle point of a set of accumulator cells. It will be seen from the diagram that the impulses of current will pass alternately into one or other of the accumulator sets, and will charge each in turn. By this arrangement the aluminium cells are not called upon to resist the full back electromotive force of the impulses in the wrong direction, for one or other of them is always open to the easy passage of current. Thus the wear and tear of aluminium is reduced, and the heating of the cells is also lessened. This is useful, because the efficiency of the valve begins to fall off when the temperature rises above 70° F.

Many different salts may be used for the electrolyte. The choice among these will be partly governed by the nature of

the metal used for the other pole of the cell, for it is desirable that this should not be attacked through electrolytic action. Nodon states that neutral ammonium phosphate is that which gives the best results. Ammonium carbonate may also be used, and the valve effect is also obtained remarkably well with magnesium in a solution of ammonium fluoride.

In the Nodon valve the solution is one of ammonium phosphate, and the aluminium poles are said to be alloyed with zinc. When the cell has been in action for a time the ammonium phosphate solution gives off ammonia, and becomes acid. Some aluminium phosphate is formed, and a crystalline precipitate gradually incrusts the interior of the cell. If the electrolyte is kept alkaline by frequent small additions of weak solution of ammonia to

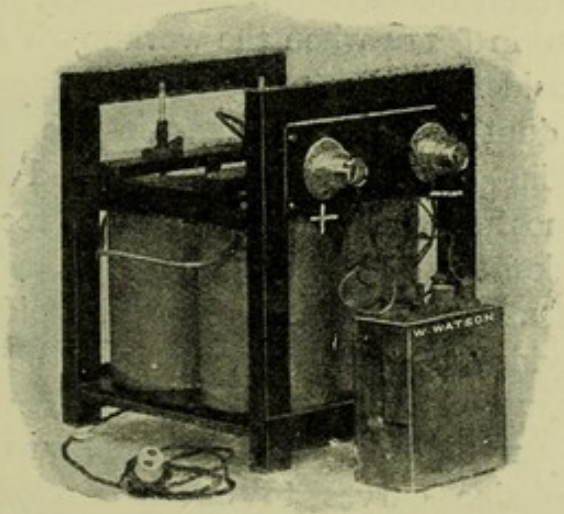


FIG. 104.—ALUMINIUM RECTIFIER.

take the place of the water lost by evaporation, this incrustation will be much diminished, and instead there will be merely a slow precipitation of alumina as an amorphous sediment. Chlorides are unfavourable to the valve effect, and distilled water must be used in preparing the electrolyte.

The solution of ammonium phosphate should be saturated. If iron plates are used in the cell, they remain unattacked, if the cell is properly managed.*

For good rectification the area of the aluminium should be

* The Nodon valve rectifier is supplied by Isenthal and Co., 85, Mortimer Street, W. The Pollak valve by Watson and Sons, 313, High Holborn. A simple aluminium rectifier for charging accumulators is made by the Aluminium Rectifiers Co., Devonshire Street, Theobald's Road, W.C.

small, so that the density of current per unit of surface is high. On this account a slender rod of aluminium is to be preferred to a sheet or plate of the metal, particularly when the currents to be rectified are not much more than one or two ampères. On circuits of 200 volts it would be economical to transform down to 50 volts before rectification, as this procedure would give four ampères for one, subject only to losses in the transformation.

The capacity (§ 11) of the aluminium valve cell is remarkably high. Apparently the rectification is due to the formation of a very thin non-conducting film of aluminium oxide on the surface of the metal when it is acting as the anode, and this film produces a condenser effect so that a large electrical capacity can be obtained by the use of the aluminium cell. This has been utilized in an arrangement known as the Grisson valve, which will be referred to in § 114 when the working of large induction coils is being considered.

If the aluminium rod be examined in the dark when the valve cell is working, it will be seen to be covered with a luminous glow, which is most marked when the cell is rectifying against a fairly high back electromotive force.

99. **A.C. Applications to Patients.**—For sinusoidal currents the A.C. mains provide exactly what is required, and only need regulation by a suitable transformer. In spite of variations of contour in the curves of commercial A.C. currents, they are close enough to sine curves to be satisfactory for medical purposes. Rectified currents are not smooth enough to use for continuous current applications. It would be possible to use a battery of small accumulator cells and to charge them through an aluminium cell occasionally as required, but it is much better to have recourse to an ordinary portable battery of dry cells (§ 72), because after all an apparatus of that kind is indispensable for electrotherapeutic purposes, on account of its portability. For the same reasons a simple induction coil driven by a dry cell will be preferred for " faradic " currents.

100. **A.C. Small Lamps and Cauteries.**—For the operation of these on alternating-current circuits a suitable transformer with regulating resistances (§ 96) is all that is required.

101. **Ruhmkorff Coils.**—These may be driven from the direct current mains in several ways, which will be more fully considered in Chapter VI. In the first place, accumulators may be charged,

and these employed to operate the coil, using a hammer interrupter and six, eight, or ten accumulator cells (12 to 20 volts). This arrangement is transportable, and will be used chiefly when X rays are required at the bedside of a patient. Or instead of the accumulator cells the current of the main can be used, its pressure being reduced by the shunt-circuit resistance method described in § 90, or the full pressure may be directly applied to the coil through a high-speed break and a series resistance.

The rectifier of Siemens enables large coils to be driven with ease from the A.C. mains. The aluminium rectifier can also be used as already mentioned; finally, the same appliance can be used to charge accumulators, and these can then be employed for the coil.

A form of turbine break actuated by a synchronous alternating motor has also been designed for use with the A.C. mains. It is

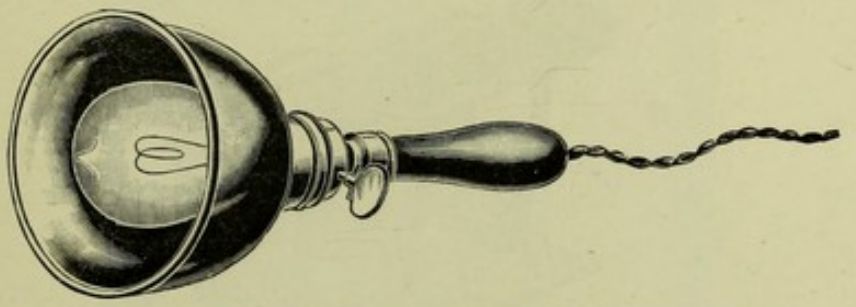


FIG. 105.—HAND-LAMP FOR THE LOCAL APPLICATION OF HEAT AND LIGHT.

fitted with a wheel by which it is speeded up to synchronism by hand.

102. **Lamps for Therapeutic Applications.**—Incandescent lamps may be used as a source of warmth as well as of light. Foot-warmers fitted with an incandescent lamp instead of the usual hot water have obvious advantages, and the principle may be extended almost indefinitely for purposes of applying heat continuously to various parts of the body.

Fig. 105 shows a form of hand-lamp which may be used for applying warmth locally for the relief of pain or other purposes, and Fig. 106 shows an apparatus fitted with lamps for application to the abdomen.

For these applications of electricity the electric light mains are required, because the amount of energy consumed in them is considerable, and much more than could be conveniently provided from batteries.

It has been claimed that the light given out by incandescent lamps has a therapeutic value above that of the heat they afford, and the use of electric light cabinets in which the whole surface of the body is exposed to the light of incandescent lamps has been very largely advocated and pushed of recent years, especially by various interested persons. It is certain that the exposure of the body to the light of incandescent lamps is a very convenient way of stimulating the action of the sweat-glands, and the effects of the hot room of a Turkish bath may be produced very simply and easily by this means. Fig. 107 shows a "cabinet" for electric lamp baths. The opening at the top is to allow the patient's head to emerge.

The earliest work on the use of incandescent lamps for sudatory purposes was done by Dr. Kellogg, of Battle Creek, in the United

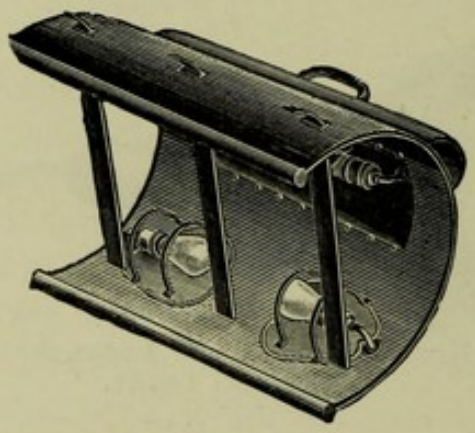


FIG. 106.—ELECTRIC LIGHT WARMER FOR THE ABDOMEN.

States, and his report on the subject was laid before the American Electrotherapeutic Association in 1894. He observed that active sweat secretion began within ten minutes from the time of exposure of the body to the light of the lamps, and found that the average temperature in the bath-cabinet was about 80° F. instead of the 140°, or higher, of the hot room of the Turkish bath. He also pointed out that the air was not only cooler but purer in the incandescent-lamp bath. It is not unlikely that the use of electric lamps may supersede the present Turkish-bath method of inducing perspiration.

In the treatment of disease the use of light and heat from electric lamps has been considerably developed in recent years. If the extravagant claims made by certain writers be disregarded it still remains that for certain purposes the use of this method

of treatment is of value, particularly in the treatment of stiff and painful joints.

103. **The Finsen Lamp.**—Arc lamps are also used for therapeutic purposes. With the arc lamp the violet and ultra-violet rays are abundant, whereas they are absent or scanty in the light of incandescent lamps. The work of Finsen, of Copenhagen, has firmly established the fact that the concentrated light of the arc lamp, or of the sun, has a curative effect upon lupus,

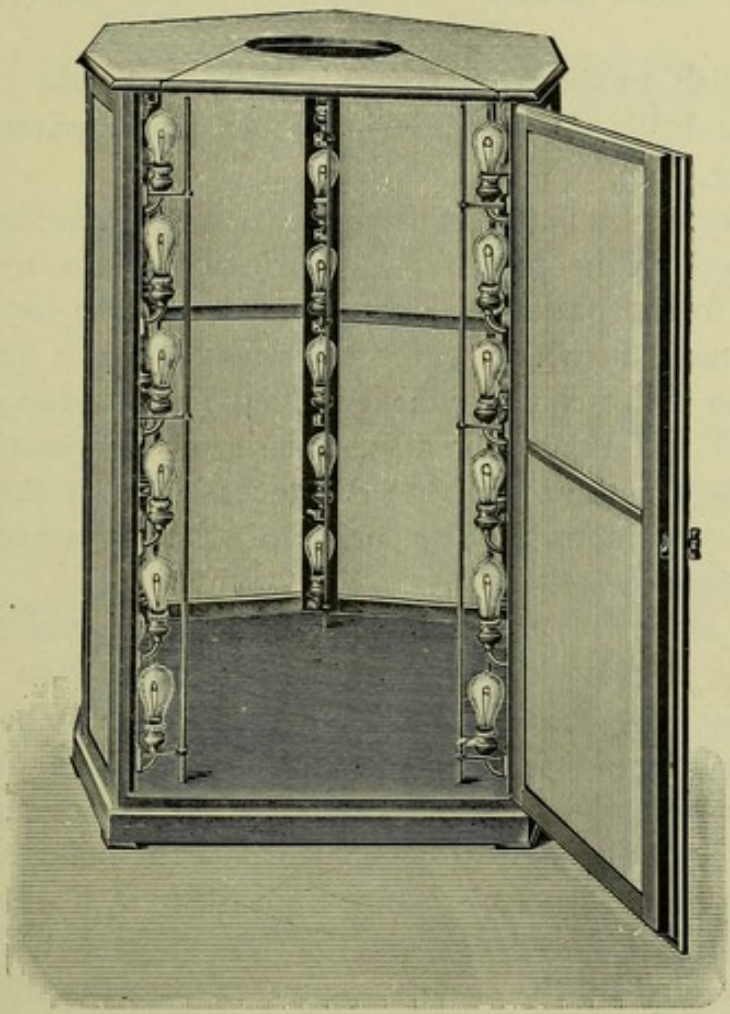


FIG. 107.—ELECTRIC LIGHT BATH CABINET.

and it is to the labours of Finsen that we owe the introduction of light as a therapeutic agent into medical practice. Finsen's apparatus consists of a very powerful arc lamp, consuming as much as 80 ampères of current, and the light from the arc is collected by quartz lenses, and focussed upon a small area of the affected surface, which is kept cool and at the same time rendered anæmic by a quartz compressor through which cold water is kept flowing. The object of the compression is to

press out the blood from the capillaries of the part under treatment, and so to facilitate the penetration of the light rays to a greater depth than would be possible in the presence of the blood, which absorbs the violet rays of the spectrum.

The great size and cost of an installation like that of Finsen has led to many attempts to obtain equally good results with simpler forms of apparatus. An arc lamp of moderate size, with a cooling shield and compressor combined, has been extensively used under the name of the Lortet - Genoud lamp.

An English modification of this lamp is made by Messrs. Marshall and Woods,* and is in use in many parts of Great Britain (Fig. 108).

In this form of apparatus the lesser power of the lamp is compensated for by the possibility of bringing the source of light very close to the patient. The carbons are close to a shield D of hollow metal in which water circulates. C is a quartz compressor, also water-cooled, which is pressed upon the part to be treated. E and B are for adjustments of the position of the lamp. A is a regulator of the distances between the carbons; F, flexible conductors. The price of the apparatus is £20, without accessories.

Fig. 109 shows a sectional view of the interior of the lens in place in the shield. The rays of the arc are thrown upon, and collected by, the convex lens E, inserted at the back of the shield, in place of the usual flat lens; they then pass to the condensing lens, C, and are focussed on to the compressor, A, the diameter of the spot of concentrated light being about $\frac{3}{8}$ in. By altering the distance of the arc from the lens, E, this diameter may be increased or decreased to a small extent. The compressor is cooled by the circulating water from the shield, which passes through the apparatus, as shown by the arrows. The lens, F, is merely for enclosing the water in the compressor, the space between F and C being air. The apparatus can be easily taken apart for cleaning by unscrewing the metal cones G and H. The distance of compressor from point of shield is three inches. Fig. 110 shows a similar apparatus known as the Finsen-Reyn lamp, which is the approved form of small arc lamp used in Copenhagen.

104. **The Condenser Spark-Lamp.**—Although the success of

* 2, Gray's Inn Road, W.C.

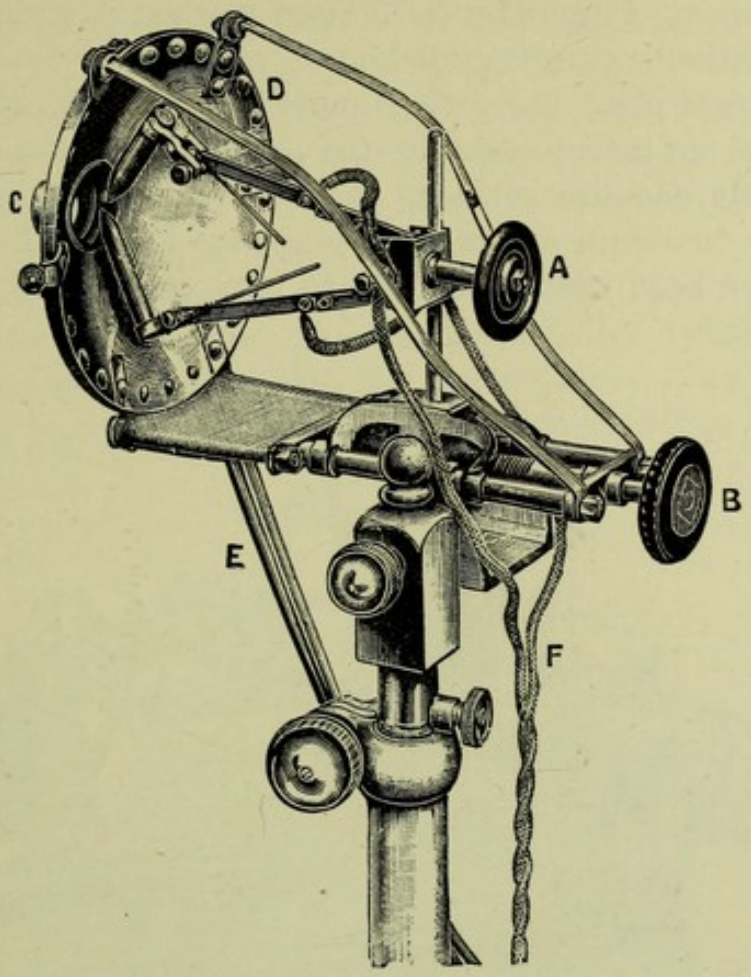


FIG. 108.—LORTET-GENOUD ARC LAMP FOR LUPUS.

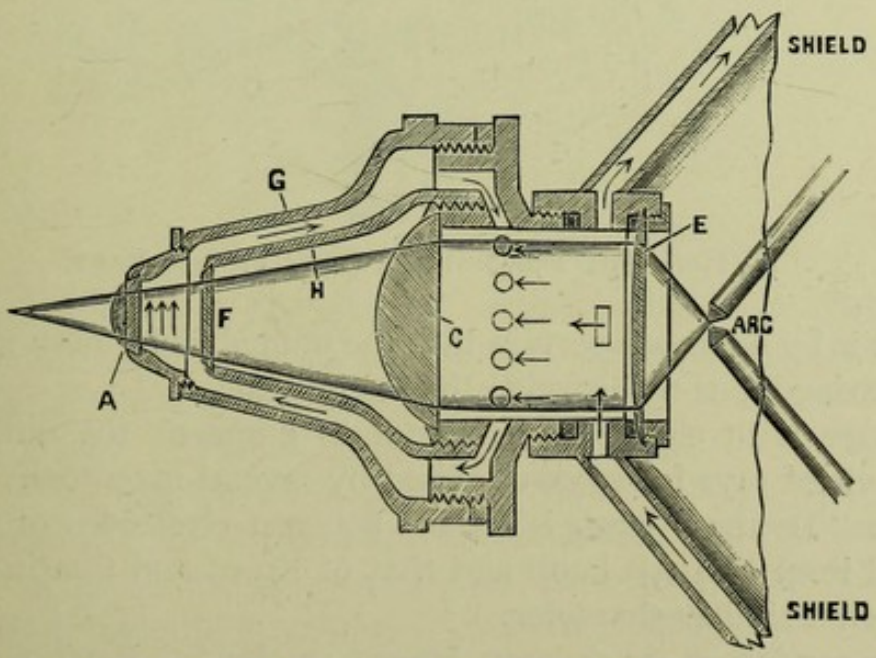


FIG. 109.—SECTION OF LENS OF THE LORTET-GENOUD LAMP, SHOWING WATER-COOLING ARRANGEMENTS.

the treatment of lupus by the Finsen method is undoubted, yet its application is extremely tedious.

In the first place, the sittings must be of long duration, thirty minutes or an hour ; secondly, the part treated at one sitting is only about one square inch, and the number of applications necessary to obtain a cure is very great. For all these reasons there have been many attempts to improve upon the method,

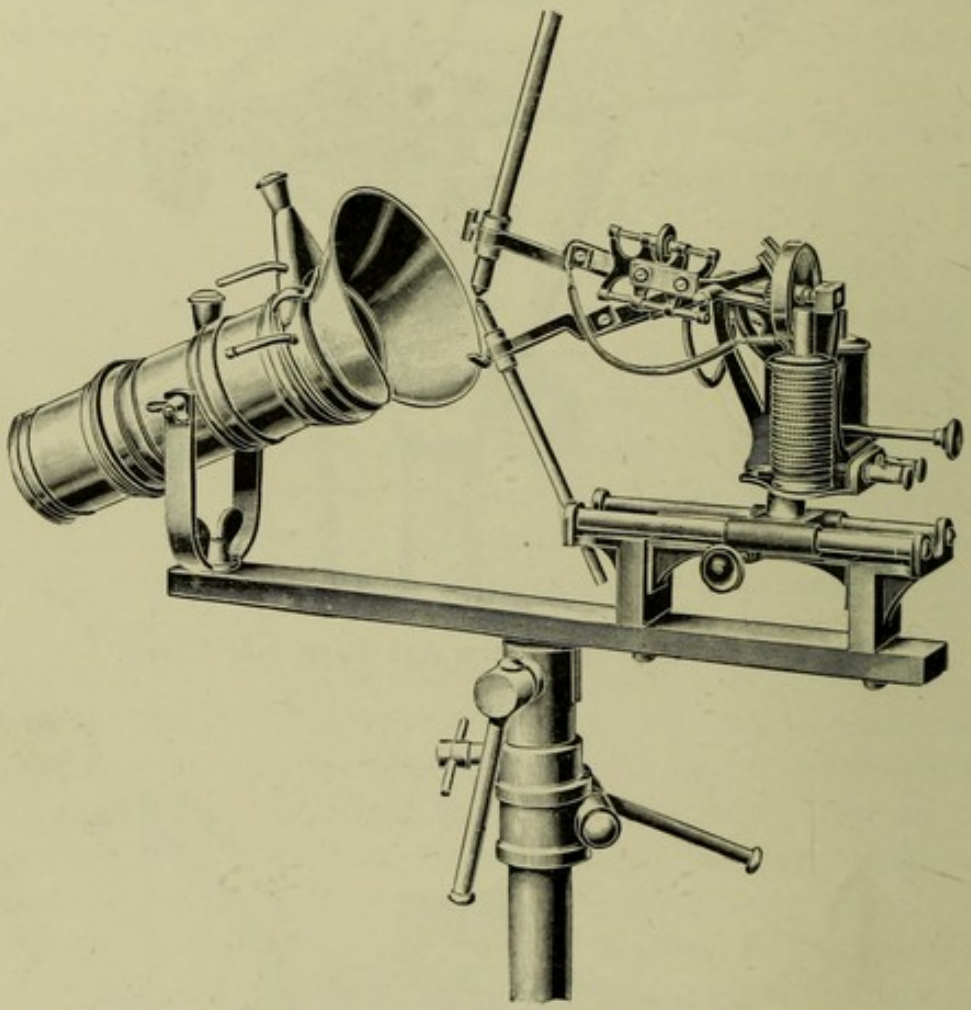


FIG. 110.—THE FINSEN-REYN FORM OF ARC LAMP.

and it is by no means certain that the unmodified Finsen method of treating lupus will survive the test of time.

Lamps with electrodes of metal to augment the output of ultra-violet rays have been devised by several inventors.

The " Dermo " lamp is an arc between electrodes of water-cooled iron. Bang's lamp and that of Broca and Chatin are of somewhat similar character.

The condenser spark-lamp known as the St. Bartholomew's lamp, made by Mr. Leslie Miller (Fig. 111), makes use of the

well-known physical fact that condenser spark discharges are especially rich in the spectral lines of their metallic sparking points. It consists of a cylindrical metallic holder enclosing a pair of iron rods between which a stream of condenser discharges is maintained. The end of the tube is closed by a window of quartz, or, better, by a block of ice, and this is pressed upon the part to be treated. If quartz is used it requires constant attention to prevent its becoming obscured by a film of ferric oxide, which is quite opaque to ultra-violet rays. The ice renews its surface by melting, and so keeps clean and free from iron

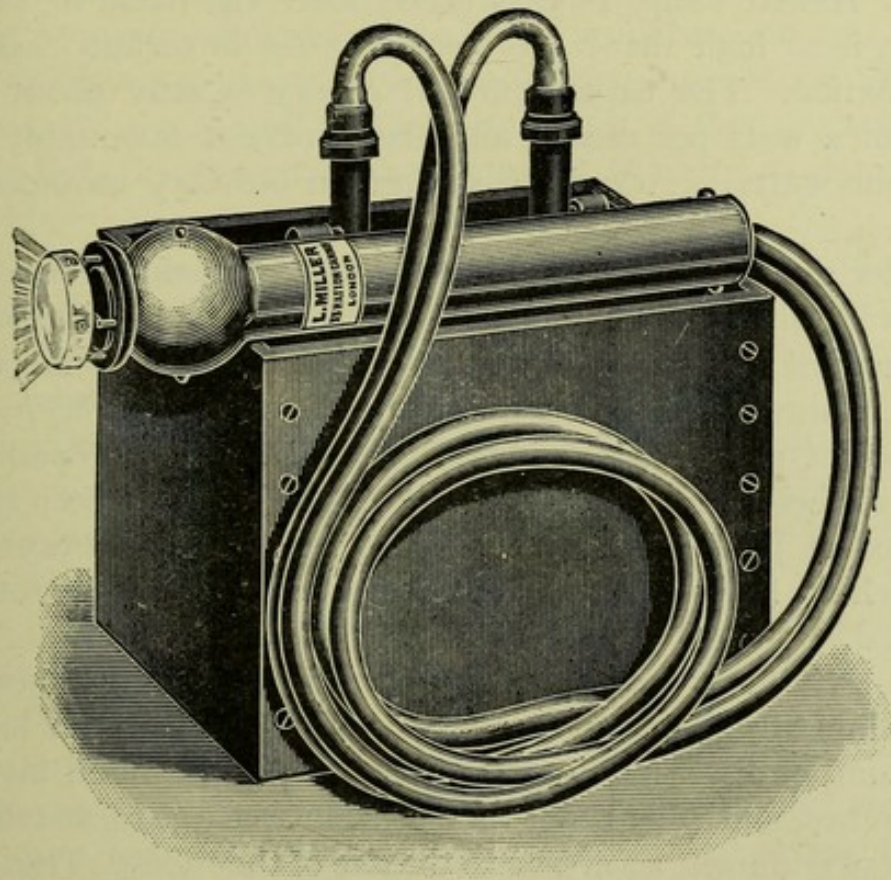


FIG. 111.—THE CONDENSER SPARK-LAMP.

oxide deposits. This lamp is rather noisy in action. The current is obtained from Leyden jars, or from an oil-immersed condenser, supplied with current from a large Ruhmkorff coil, or from a high potential transformer at about 6,000 volts connected to the alternating electric light mains. As a source of ultra-violet rays this instrument is unequalled. In the treatment of lupus it has proved itself of genuine utility, and it possesses certain advantages over the large and expensive carbon arc lamps, not least of which is the smaller proportion of heat rays which it gives out.

105. **The Cooper Hewitt Lamp.**—This apparatus consists of a glass tube exhausted of air, and containing mercury and mercury vapour. When traversed by a current, the tube becomes filled with a brilliant light which is of a peculiar colour, and shows, if examined with a spectroscope, a line spectrum rich in green, blue, and violet lines, but very deficient in red. On this account the appearance of coloured objects, when viewed by the light of the mercury vapour lamp, is peculiar. The face and hands present a dull leaden hue, which is very unpleasant. Nevertheless, the efficiency as a source of light of the mercury vapour lamp, or Cooper Hewitt lamp, as it is called after the name of the inventor, is so high that it has come into use for certain classes of illumination. The expenditure of energy is only about one-third of a watt per candle, and this contrasts favourably with the four watts per candle consumed in ordinary incandescent lamps.

Under the name of "The Uviol Lamp," a modification of the Cooper Hewitt mercury vapour lamp has lately been introduced into medical work. We have already seen that the illuminating power of these lamps is high, and their light is also very rich in ultra-violet rays, but the glass wall of the tube is opaque to many of these actinic radiations. Glass has recently been manufactured at Jena which is pervious to the ultra-violet rays, and Dr. Schott has made the envelope of the new lamp of this material.

The Uviol lamp consists of a tube of this special glass of 8 to 30 millimetres diameter and 20 to 130 centimetres in length. Platinum wires terminating in carbon heads are fused into the extremities, and in addition they contain a charge of mercury of 50 to 150 grammes, according to the size of the tubes. The lamps are of various sizes. They are provided with resistances and choking coils, and can be connected directly with electric mains of 220 or 110 volts.

To start the arc, the lamp is tilted to a sufficient degree to allow of the mercury in the tube passing from one pole to the other. At the moment of contact between the pole and the mercury, part of the latter is disintegrated simultaneously with the formation of a column of light. The carbon heads to the poles permit the passage of the current in either direction without fusing the platinum leading-in wires. To get the best results from a current of 220 volts, the lamp tube should be 130 centimetres

long, but two or more shorter lamps may be arranged side by side.

The spectrum of the Uviol lamp is exceedingly rich in lines in the violet and ultra-violet parts of the spectrum, and it appears likely that it will prove of value in the treatment of lupus. It is an irritant to the eyes, so that operators should wear spectacles when working with it. The cost of a 400- to 800-candle lamp is stated to be between 1d. to 2d. per hour.

106. **Motors.**—D.C. motors, like dynamos (§ 49), may be either shunt wound or series wound. The small machines used in medical work are usually shunt wound, and their speed is regulated by means of a resistance in the armature circuit. Before switching on a motor, it is very necessary to be sure that the whole resistance is included in the circuit, for if this precaution be neglected, the sudden rush of current is likely to damage the machine.

For instruments whose movement must permit of sudden stoppage, a switch is designed which cuts off the exciting current, and short circuits the armature windings at the same time by connecting the commutator brushes. This has the effect of converting the motor, temporarily, into a dynamo with a current of large magnitude passing across the brushes. This acts as a heavy load, and stops the movement of the armature by absorbing its kinetic energy.

A little attention given periodically to the commutator and the brushes of a motor will be well repaid in the smooth and equable running of the machine.

Alternating motors are now made by several firms, and, apart from the question of starting, they are excellent machines. For the most part they belong to the class of " induction motors," and have no commutators and brushes; consequently they need less attention than D.C. motors.

Hitherto their weak point has been that they do not start well when loaded, and some arrangement with a loose pulley is generally necessary to enable the motor to be run up to speed on no load. When running steadily the load can be slipped on. Every year improvements are being made in this respect, and an A.C. motor to start on a load is now attainable. Speed regulation is another weak point of A.C. motors which is in process of improvement. In other respects alternating motors are very good machines, and give little or no trouble.

107. **Dangers of Electric Lighting Mains.**—In all applications of current from the mains to patients it is necessary to take proper precautions to prevent accidents. These may arise from defects in the design of the apparatus, either inherent, or as a result of wear and tear, from loose connections, etc. Care must always be taken to avoid the risk of discharges to earth through a patient, as it is quite possible to have things so arranged that the patient might receive a dangerous discharge from one pole of the apparatus to earth, even when employing resistances in such a way as to prevent dangerous discharges from pole to pole through a patient. For instance, if all the safety resistance should be on one side of the patient, and there were none on the other, an accidental contact of the patient with a good earth, as through a gas or water pipe or a damp wall or floor, might expose him to a leakage to earth at a high pressure.

On circuits of 100 volts this is bad enough, but when the differences of potential possible in a lighting company's network are 200 or 240 volts, or even more, it becomes obvious that the danger is not an imaginary one.

Another matter to be attended to in shunt circuit regulation is the maintenance of the continuity of the resistance wire. If it should break from any cause, or become disconnected at one extremity, the patient might receive the full pressure of the mains, if his circuit bridged the interval of the gap. In general, the lamp resistance provided on the shunt circuits acts as a safety indicator. If it should not light up as usual, or if it should light up too brightly, it must be taken as a warning that something needs attention.

With electric baths, where the patient is largely deprived of the protection generally afforded him by the resistance of his skin and clothing, special attention must be given to the dangers of shock to earth. Quite apart from the matter of electric baths, it may be laid down as an axiom that no metal connected in any way to an electric light fitting should be in reach of any person in a fixed bath of any kind. Electric light switch covers may be alive, from accident or bad workmanship, and if so a person standing in a bath, with pipes and taps of metal attached to it, might easily be killed by touching one.

The accidents at the Fulham baths at the end of 1902 occurred in this way. Two men standing in water, or on a wet bath-room floor, touched an iron pipe, which happened to be alive

through defective wiring arrangements for the lighting of the building, and both were killed by a pressure of 200 volts.

It is useless to attempt to insulate a bath if it is fitted with metal water-pipes and waste pipe. It must be regarded as permanently earthed, and protected efficiently from that point of view, if it is to be a safe appliance.

For sinusoidal current baths protection may conveniently be ensured if the regulating transformer be made with a sliding secondary coil having an air space or an ebonite sheath between it and the primary windings. With direct current mains much security will be afforded by the use of a battery of accumulators for the bath. These may be charged from the mains as required, but should be provided with an interlocking safety switch to compel the cutting off of the mains current before the bath circuit can be connected.

CHAPTER V

HIGH POTENTIAL APPARATUS—THE RUHMKORFF COIL—TRANSFORMERS

Ruhmkorff coils—Interrupters—The turbine jet-break—Wehnelt's electrolytic interrupter—The Grisson apparatus—Spark lengths—Current waves of coils—High potential transformers—Rectifiers of high potential currents.

108. **The Ruhmkorff Coil.**—The full-powered induction coil has become an instrument of great importance in medical practice in recent years. This is due mainly to the developments of X-ray work, but also in part to the use of currents of high frequency in medical treatment, and to the use of condenser spark-lamps in phototherapy. In all of these applications the apparatus most generally employed for supplying the required high pressures is the Ruhmkorff coil. The impetus which has been given to the manufacture of large induction coils for such applications has led to many improvements in coils, especially in the direction of their adaptation for use upon electric lighting circuits, which has required the evolution of new forms of interrupter. The general principles of the induction coil have been already considered in § 48, and further details of the characteristics of small medical coils will be found in §§ 59-61. Ruhmkorff coils are commonly classified in terms of the length of spark which they are capable of giving. Thus, a twelve-inch coil signifies one which can give a spark twelve inches long. Ten, twelve, and even eighteen inch coils are now in common use for medical purposes.

These large coils require to be manufactured with care, and with attention to detail in every part. The primary windings are of two or three layers of thick copper wire, for they have to carry currents of considerable magnitude without becoming heated. A plug or switch arrangement is used in most modern coils for connecting its layers in shunt or in series, and thus of varying the self-induction of the primary circuit as may be desired

to suit the pressure of the source from which it is driven. The massive iron core is finely laminated to facilitate the magnetic changes which are to take place in it. A solid bar of iron would not do, because it would be a source of great loss of energy through becoming the seat of induced currents or "eddy" currents, which would heat the core and dissipate energy, and would also retard the decay of its magnetic field, upon the suddenness of which the efficiency of a coil depends so largely.

The following data of a ten-inch coil, as given by Professor J. A. Fleming,* are useful as a guide to the approximate dimensions of such instruments. He writes: "The primary circuit of this coil consists of 360 turns of No. 12 copper wire, and has a resistance of 0·36 of an ohm, and an inductance of 0·02 of a henry. The secondary consists of ten miles of No. 34 copper wire, making about 50,000 turns. It has a resistance of 6,600 ohms, and an inductance of 460 henrys. The mutual inductance between the primary and secondary circuit is 2·74 henrys."

To secure a good and lasting insulation of the secondary coil is essential. The core, after being wound with the primary wire, is usually enclosed in a thick vulcanite tube. On the latter the secondary wire is wound in sections. In small induction coils

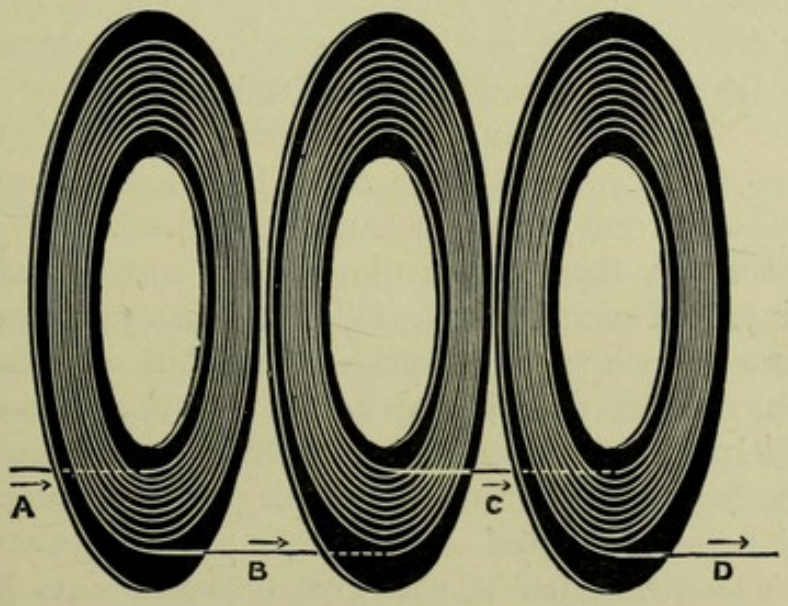


FIG. 112.—PLAN OF WINDING IN THE JOINTLESS SECTION COILS.

the secondary is wound in single layers along the length of the bobbin, like cotton on a reel; but large coils are wound in sections, an arrangement which may be compared to a row of reels arranged

* Cantor Lectures, 1903. On Hertzian Wave Telegraphy.

side by side on a spindle, with the ends of cotton carried from one reel to the next.

Although some makers of good coils still wind them in two sections only, most first-class coils are now wound in many sections, and a twelve-inch coil may have seventy or eighty of these sections arranged side by side, and separated from one another by thin discs of ebonite.

The sectional construction is adopted in order that there shall not be any great difference of potential between contiguous portions of the secondary coil. The sectional construction has been developed to its highest degree in the "jointless section" coils of Mr. Leslie Miller. In his coils, every single winding consists of one flat spiral of wire, and has its corresponding insulating layer of waxed paper, so that the completed secondary coil has from 700 to 1,200 single layer sections, according to its size. The extra care thus taken in the insulation of the secondary serves to diminish the number of turns of wire necessary for a given length of spark, and thus reduces the resistance of the coil and its impedance, and the sparks of such a coil are consequently thicker, and the quantity of current in the discharges is increased.

The output of a coil, though commonly estimated by its simple sparking distance in air, can be better estimated by observing the length of spark when Leyden jars are connected to its secondary terminals. The reduction of spark-length produced by the introduction of a condenser of given capacity is less the greater the magnitude of current in the discharges of the coil.

In writing on this subject of coils for wireless telegraphy, Professor J. A. Fleming has the following observations: "A coil may give a 10-inch spark if worked alone, but on a capacity of $\frac{1}{30}$ of a microfarad (§ 25) it may not be able to give even a five-millimetre spark. Hence in describing the value of a coil . . . it is not the least use to state the length of spark which the coil will give between pointed conductors in air, but we must know the spark-length which it will give between brass balls, say one centimetre in diameter, connected to the secondary terminals when these terminals are also connected to a stated capacity." These remarks apply to most of the purposes for which coils are used in medical work, and especially in the case of high-frequency applications.

The appearance of the completed coil is well known (Fig. 113).

In a box below the board on which the coil is mounted, and forming part of the base of the instrument, is placed the condenser. This consists of a number of sheets of tinfoil, insulated from each other by sheets of paraffined paper. The metallic sheets are connected in two sets, the even numbers on one side being connected to one of the two supports of the contact breaker, and the odd numbers on the other side to the second support. The object of the condenser is to accelerate the rate of decay of the current in the primary circuit, as the efficiency of the coil depends upon the suddenness with which this is accomplished. When the current from the battery is broken, the heat and the spark at the point of rupture tend to prolong the time during which current can pass, and make the interruption, to a certain extent, a gradual one. The condenser is of

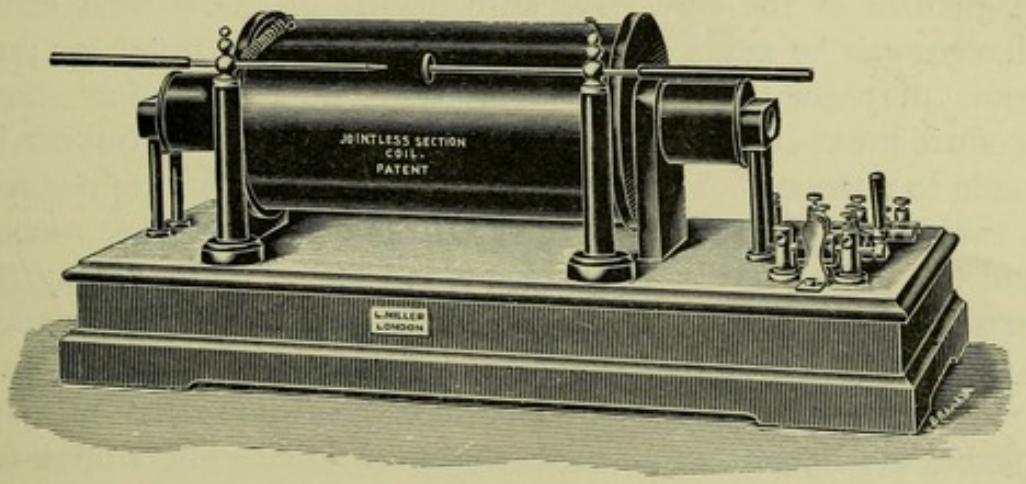


FIG. 113.—MODERN RUHMKORFF COIL, WITHOUT HAMMER.

service by reducing the amount of the sparking, for the electromotive force induced in the primary wire by the rupture of the circuit is diverted into the condenser, charges it, and then discharges back through the primary winding, producing a momentary reverse current, and through it accelerating the demagnetization of the core. With very sudden interruptions the condenser ceases to be necessary.

At the side of the contact breaker is usually found a commutator switch for reversing the direction of the current in the primary circuit. It also serves for turning the current on and off.

It is advantageous to arrange the condenser so that the whole or part can be used. If it be divided so that one-third, two-thirds, or the whole can be employed, it is sufficient for medical purposes. The same coil can be made to work to its full power,

using either an accumulator of 8 or 12 volts or a pressure of 100 volts from the street mains, if the primary windings and also the condenser be subdivided and adjusted.

109. **Interrupters.**—The contact breakers of large coils may either be of the vibrating hammer type, like those used in medical induction coils, or a motor-driven interrupter may be used, or the electrolytic break of Wehnelt can be employed. The ordinary hammer is not yet abandoned, and has its uses chiefly in portable coils. Much of the work done with X rays, even with ten and twelve inch coils, is still carried on with the vibrating hammer interrupter, although it is greatly inferior to the mechanical breaks shortly to be described. Hammer interrupters for spark coils are fitted with a "tension screw," by turning which the hammer can be made to resist the pull of the magnetism of the core. By adjustments of the tension screw changes can be made in the working of the interrupter for purposes of regulation. Small alterations of the tension screw produce great effects in the length of spark which the coil can be made to give out. Thus, with the tension of the spring relaxed, a twelve-inch coil may only give sparks of two or three inches, and the sparks can be made longer and longer by increasing the tension of the screw. Thus, at times it will be advantageous to screw up the tension spring as tightly as possible, short of preventing its movement. Under these conditions the primary current is only broken when the full magnetizing effect upon the iron core is developed, and a sudden break of current at this moment gives the maximum effect of which the coil is capable. When working with a tightened tension spring, it is necessary to remain near the apparatus while it is at work, as under these conditions the platinum points of the vibrator may stick together, and so permit a rush of current which may damage either the accumulators or the primary coil. The platinum contacts of the interrupter burn away gradually from the action of the spark, and their surfaces become uneven and need to be filed smooth from time to time if the coil is to work satisfactorily.

In an improved form of hammer break, of which the "Vril" interrupter is an example (Fig. 114), the iron hammer C and the platinum points F are carried on separate springs.

When in action, the movement of the hammer causes the point of the screw D to impinge on the top of the spring B, so striking apart the platinum points F, and making their separation a

sudden one. Another advantage of this break is that the period of contact is a more prolonged one, giving time for a more

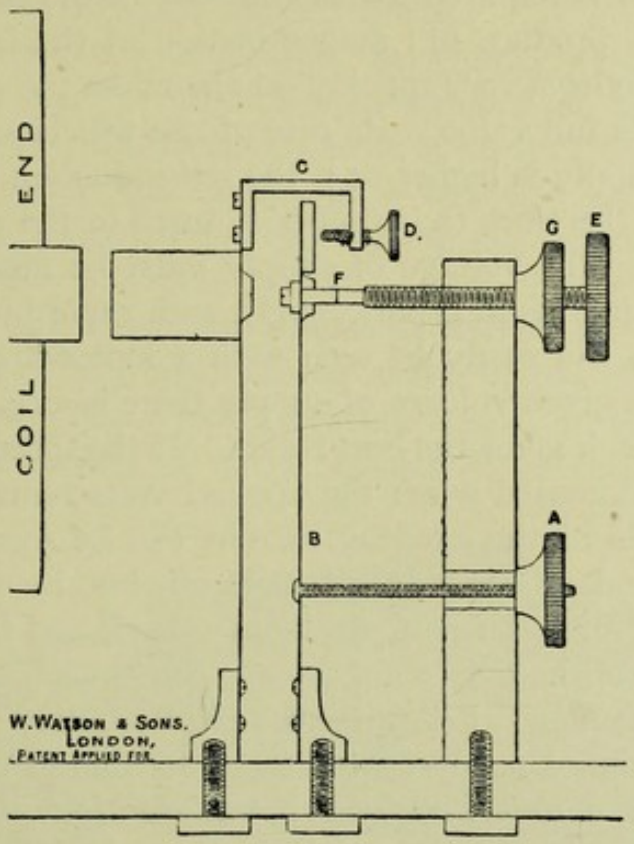


FIG. 114.—VRIL INTERRUPTER.

A, Head of tension screw; F, platinum contacts.

thorough magnetic saturation of the core. The screws D and E with the lock-nut G permit of adjustments.

Messrs. Gaiffe have recently brought out an interrupter which embodies the same principle, and is called the Carpentier-Gaiffe interrupter. It is small and light, and may be used with advantage in portable coils for X-ray work at the bedside.

For steady work with large coils, and for the comfort and convenience of the operator, the hammer interrupter is unsuitable, and must be replaced by some form of mechanically driven motor break, or by the electrolytic breaks of Wehnelt or Caldwell.

In many applications of Ruhmkorff coils it is necessary that the interruptions should follow one another in rapid succession, but high-speed breaks require high electromotive forces to give good results. Consequently there is not much advantage in using a rapid break unless the electromotive force applied to the primary is high.

An ordinary 12-inch coil that works perfectly well with a plati-

num break and a few cells of an accumulator will not give sparks of the full length of 12 inches with a high-speed break, because a certain time is required for the current in the primary to rise sufficiently to produce full magnetization of the iron core, and if the break follows very quickly on the make the current never does rise to its full value. Its rate of rise will be quicker if the pressure of supply is higher or if the self-induction in the circuit is lower, and therefore the number of turns in the primary must be reduced, or the voltage of supply must be increased, if the current is to give its full spark-length with rapid breaks.

This action can easily be seen with a motor-driven mercury break. For a given voltage of supply there is a certain speed of the motor which gives the best result. If the speed of the interruptions be increased when the applied volts remain the same, the magnitude of the exciting current can be seen to decrease and the secondary spark-length falls off, but by increasing the voltage the primary current can be increased, and the full spark-length re-established.

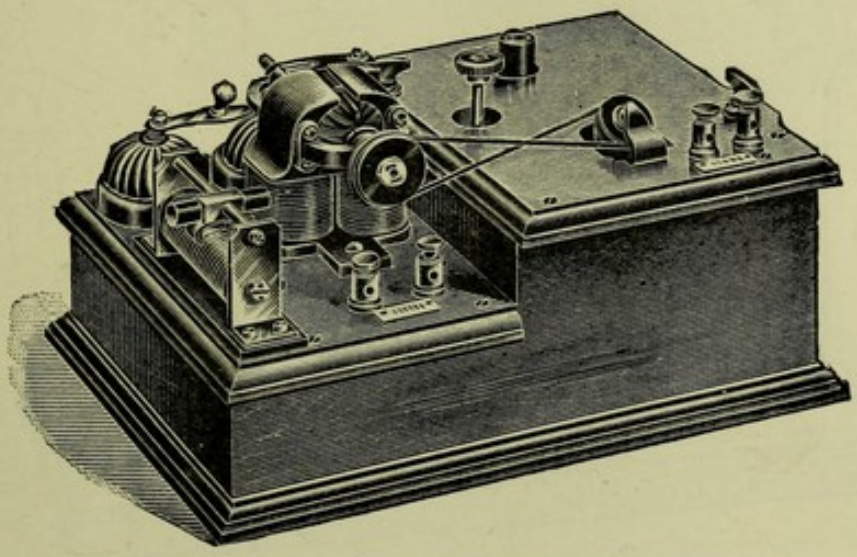
With the hammer interrupter the electromotive forces applied to the coil cannot safely be increased beyond a certain point, whereas with a motor-driven break electromotive forces up to 250 volts may be employed if necessary, provided the speed of the break be increased in due proportion; and in this way we arrive at the direct employment of the direct current electric lighting mains for working large coils, a method which is only possible with rapid interrupters. With pressures of 200 volts, the electrolytic break of Caldwell can also be used, for this gives even more rapid interruptions.

110. **Mechanical Interrupters.**—Many forms have been devised, and for purposes of description they may be arranged in groups. The oldest form is one in which the contacts are made and broken by a rod dipping into and out of mercury. The movement is effected by a motor the speed of which can be varied. The range of movement of the plunger which dips into the mercury can also be adjusted, and the best conditions are obtained when this is in contact with the mercury for a relatively long part of the period, and leaves the mercury when moving with its greatest velocity, which is when the crank is horizontal. These "dipper" mercury breaks are useful for medium speeds, but at high speeds the surface of the mercury is displaced, and the interruptions tend to become irregular.

For the high speeds which are necessary with high pressures of supply, a rotary interrupter with mercury is a more satisfactory instrument than a " dipper " break.

Whenever mercury is used in these interrupters it is kept covered by a layer of alcohol or of paraffin oil, to quench the sparks. Of these the former is to be preferred, because it gives far less trouble in the matter of cleansing. As these liquids become dirty, owing to the emulsifying effect produced by the churning movements of the apparatus, they require renewal from time to time, and the mercury must be cleaned and filtered.

Among the rotary breaks using mercury, two of the simplest and best are the Mackenzie Davidson break and the Turbine or Jet break. The first of these consists of an inclined metallic



MEDICAL SOCIETY OF LONDON 11, CHANDOS ST. CAVENDISH SQ. Established 1773

FIG. 115.—MACKENZIE DAVIDSON'S INTERRUPTER.

axle with projecting blades at its lower end. When the axle is revolved these make a succession of contacts with the surface of a layer of mercury. It can be driven at a high speed, which is regulated by a resistance in the motor circuit.

The turbine break (Fig. 116) is a motor-driven interrupter, in which mercury is propelled by a centrifugal pump in a continuous stream in a horizontal direction. The mercury jet strikes periodically on contacts and completes the circuit. Numerous modifications of this interrupter exist. Thus, in some forms the mercury jet is stationary, and the interruptions and contacts are made by a deeply-toothed cylinder of metal, which revolves around it. In others the jet itself revolves, and in its revolutions projects the stream of mercury against pairs of conducting arma-

tures, and so closes the circuit at periodic intervals. The armatures are made in several widths, giving different durations of the periods of closure, to suit the pressures of current to be used, and the duration of each period of closure can be further controlled by the movement of a handle, which displaces one of the armatures in the manner described in § 63 (see Fig. 39). The number of interruptions per second is regulated by varying the speed of the motor. This form of turbine break (Fig. 116) will stand heavy work, and may be used for long periods without attention. The armatures gradually wear away, but they can readily be replaced. In the forms of turbine interrupter with

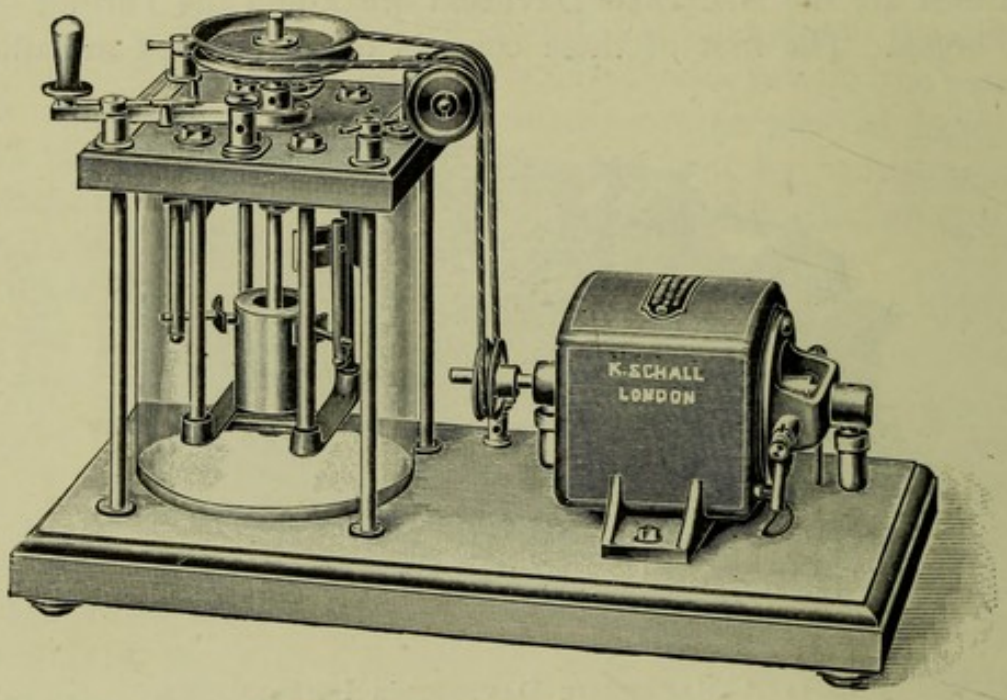


FIG. 116.—MERCURY JET (TURBINE) INTERRUPTER.

fixed jet, the duration of the contacts is varied by raising or lowering the revolving toothed cylinder, which has its segments tapered off below for this purpose.

These interrupters are to be found, with various modifications, in the catalogues of different instrument-makers. In some forms the motor is fixed in a vertical position, so as to drive with a straight belt, while in others the motor is horizontal, and the belt runs over guides. In Gaiffe's auto-motor jet interrupter the separate motor is abolished, for the current passing to the primary of the coil traverses four short electromagnets fixed on the cover of the instrument, and these set in motion a knobbed iron disc which operates the mercury jet. This is an

ingenious interrupter, which is likely to come into extended use on account of its simplicity and cheapness. The whole apparatus is contained in an iron vessel, and can easily be carried to the bedside. The internal mechanism is as follows: At the lower end of the revolving axis there is an inverted cone of iron, which is partly submerged below the level of the mercury. This cone is pierced by a canal which is obliquely inclined to the vertical axis in such a way that on its rotation the mercury, which at rest fills the lower half of the canal, is driven centrifugally

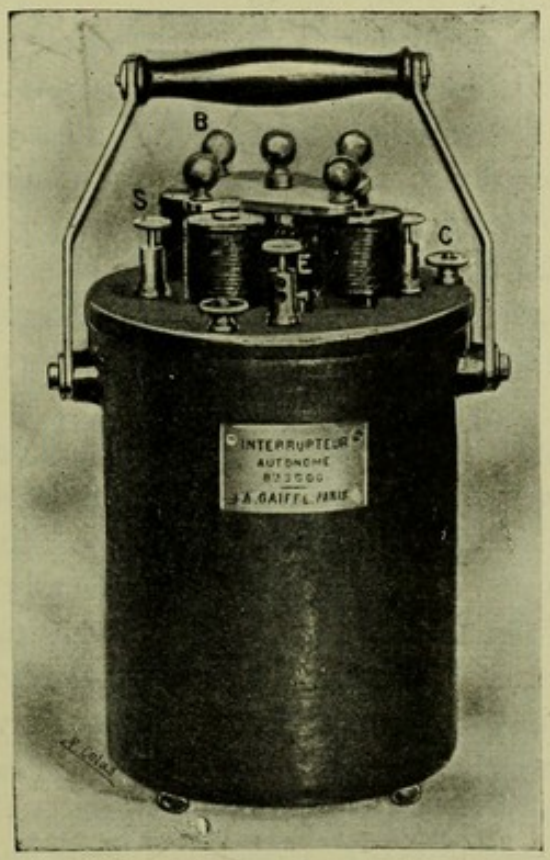


FIG. 117.—GAIFFE'S AUTOMOTOR JET INTERRUPTER.

upwards and outwards so as to jet against four fixed copper sectors which are attached to a metal crown insulated from the rest of the apparatus. The width of the copper sectors determines the duration of the contacts, and is arranged to suit the voltage from which the interrupter will be worked (Fig. 117).

The speed of rotation can be varied by a small regulating resistance in shunt to the motor coils on the lid of the instrument.

The sectors take the wear and tear, and are easily renewed or changed.

In the Contremoulins-Gaiffe interrupter, which resembles the

turbine interrupters in general appearance, revolving sectors of copper make and break contact through copper brushes beneath a thick layer of paraffin oil. The rubbing contact surfaces may be amalgamated, but no large quantity of mercury is needed, as it is in the turbine break, and cleaning is therefore a simpler process, as little is needed beyond the periodical renewal of the oil.

111. **Electrolytic Breaks.**—The liquid or electrolytic break of Dr. Wehnelt is a peculiar form of interrupting device, which depends for its effect upon the formation of gas and steam at the poles of an electrolytic cell when that pole is of small area and the current is large. A considerable amount of heat is generated, and steam is formed. This steam with the gas liberated by electrolytic action forms an insulating envelope, which interrupts the current. This is followed by the disappearance of the insulating layer, the current is re-established, and a fresh production of gas occurs. Thus the current is made intermittent, and the interruptions follow each other with extreme rapidity.

Wehnelt's break, as usually constructed, consists of a jar containing dilute sulphuric acid; the kathode is a lead plate, while the anode is a platinum wire enclosed in an insulating sheath except at its extremity, which is deeply submerged in the electrolyte. Means are provided for increasing or decreasing the exposed area of the wire. When a steady electromotive force, which must be of at least 24 volts, and may be as high as 150, is applied to the apparatus, arranged in series with the primary circuit of a coil, the discharge through the circuit thus formed becomes intermittent, a peculiar shrill note is given out by the electrolytic cell, and streams of sparks are given off by the secondary coil. The spark produced at the moment of rupture is thought to exercise an important influence upon the dissipation of the insulating layer, for it is found that the Wehnelt break will only work on circuits of high self-induction in which, of course, the spark at break is considerable. Care must be taken to ascertain the direction of the current before connecting up the Wehnelt interrupter. If connected wrongly the apparatus either works badly or fails to work at all, and the platinum point will probably fuse and be destroyed. The wear and tear of the platinum is trifling, and the apparatus requires less attention than any other form of interrupter used with large coils. The

interruptions are so sudden that the coil works quite well without a condenser, and this is usually cut out of the circuit when a Wehnelt interrupter is used. The apparatus ceases to act at a temperature of 90° Cent.

It is probable that the failure of the action when the electrolyte is hot is due to imperfect condensation of the steam by the surrounding liquid under those circumstances.

The sheath of the anode is made of hard porcelain. After long use it tends to become disintegrated at its extremity, and must be ground smooth from time to time. The liquid rises inside the sheath, and a small overflow channel is generally

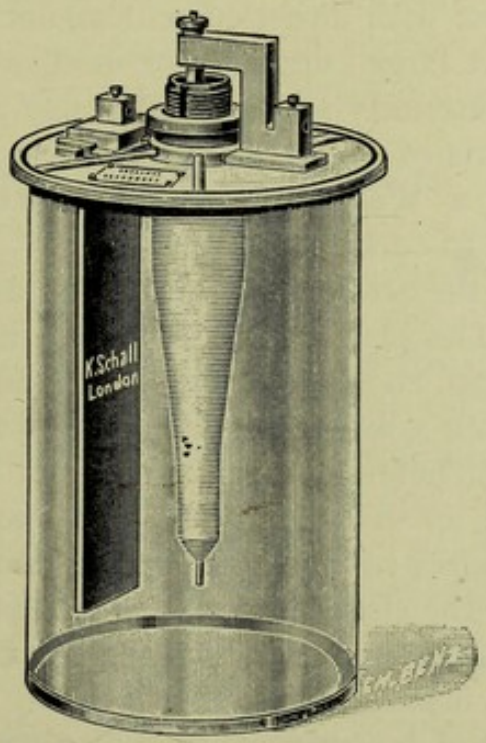


FIG. 118.—WEHNELT INTERRUPTER.

provided for its escape above the level of the liquid in the jar. It can then drip back again into the cell without providing a bye-path for current between the poles of the cell.

A saturated solution of alum containing a little sulphuric acid is also said to work well at low voltages. E. Hauser* states that with a solution containing 20 per cent. of magnesium sulphate (specific gravity 1·305) acidulated with sulphuric acid the interruptions begin at 10 volts. A solution of potassium bichromate has also been recommended for use in the Wehnelt

* *Archives of the Roentgen Ray*, December, 1904.

interrupter. These modifications have not yet been brought into general use.

When first applied to practical work the conditions for successful working with the Wehnelt interrupter were not understood, and when the full pressure of the electric lighting mains were applied the discharges obtained with this form of break were so rapid that the coils were unable to respond satisfactorily, and did not give their full rated spark-length. The electrolyte also became heated, and ceased working. In the modern forms of Wehnelt interrupter these defects have been corrected, and there is no doubt that this type of interrupter has the advantage of simplicity, and, if suitably regulated, it is a very useful interrupter for use with direct current mains. The chief objection to it is that large currents are used, a considerable part being expended uselessly so far as efficiency is concerned, while the heating effects of the large currents are troublesome. The current through a Wehnelt interrupter often reaches magnitudes of from 12 to 20 amperes.

The heating of the acid is best met by the use of large volumes of electrolyte. The glass vessels originally used contained less than 2 pints of acid, and this became heated so quickly that after about half an hour's use the interruptions stopped. By using vessels capable of holding several gallons of liquid the heating effect is reduced, as such quantities will stand an hour's use, or even longer, before reaching the critical temperature.

The cooling of the electrolyte by the circulation of cold water in a tube running through or around it has been proposed, but the complication introduced by this is better avoided.

The electrolytical interrupters make a peculiar noise when in action, but, as they require little attention after they have been properly adjusted and connected, they can be placed in another room if the noise is found to be disagreeable.

To control the Wehnelt interrupter, one may vary the exposed surface of the platinum anode, or the pressure of supply, or the degree of self-induction in the primary coil.

By increasing the surface of the platinum the current is increased, and the rapidity of the interruptions diminishes; and by reducing the exposed surface of the platinum the opposite effect is obtained. A screw arrangement for adjusting the length of the projecting platinum is usually fitted to the apparatus, and as metal screws are soon corroded by the acid fumes, this

screw should be made of ebonite. By using two or more anodes with different lengths of platinum in the vessel, a selection of the one most suited for any given tube can be effected by a simple switch.

The frequency of the interruptions is influenced by the pressure applied to the primary circuit. The higher the pressure the greater is the frequency, and *vice versâ*. It is, therefore, a convenience to have some means of reducing the pressure applied to the coil, and the use of a shunt resistance (§ 89) enables this to be done.

The effect of self-induction in retarding the growth of current in the exciting circuit of a coil has been referred to already (§§ 47, 61), and comes into especial prominence in working with the Wehnelt interrupter, and it is in connection with the use of electrolytic interrupters that a variable primary coil is chiefly required.

When all the primary windings are in series the self-induction is highest, and the spark-length which can be obtained with the Wehnelt break is short; when they are connected in parallel the self-induction is low, and the sparks are longer. By attention to these different factors—viz., the length of the anode, the voltage of supply, and the self-induction of primary coil—it is possible to obtain excellent control of the electrolytical interrupter, and the number of sparks per second can be varied from about 10 up to 1,000. To obtain long sparks a low self-induction with a long platinum pin is used, and with a high self-induction and a short platinum pin the output of the largest coils can be lowered, so that short sparks are produced.

112. **The Caldwell Interrupter.**—In Wehnelt's apparatus the intermittent character of the discharge is due to the formation and dissipation of gas bubbles at the anode. There is a modification of the electrolytic interrupter, which is due to Caldwell, and independently to Simon, in which the formation of bubbles of gas is brought about at a point in the cell remote from the poles, and thereby certain advantages are secured. It consists of a cell containing dilute sulphuric acid and two plates of lead, which serve as anode and kathode. A partition of glass or porcelain separates the cell into two parts, each containing one of the metallic poles. This partition has a small hole, through which the liquids in the two portions of the cell communicate. At this narrow opening the density of the current is very high,

heating takes place, and bubbles of gas (steam) are generated there and break the circuit; the bubbles are almost instantaneously dissipated and as quickly renewed, the rate being in part determined by the size of the hole.

In its usual form the apparatus consists of a jar containing an inner cylindrical vessel of glass, suspended so that it does not rest upon the bottom.

Connections are made by means of terminals attached to two lead electrodes, placed in the inner and outer vessels respectively. When operating, the liquid is found to rise in the inner cylinder,

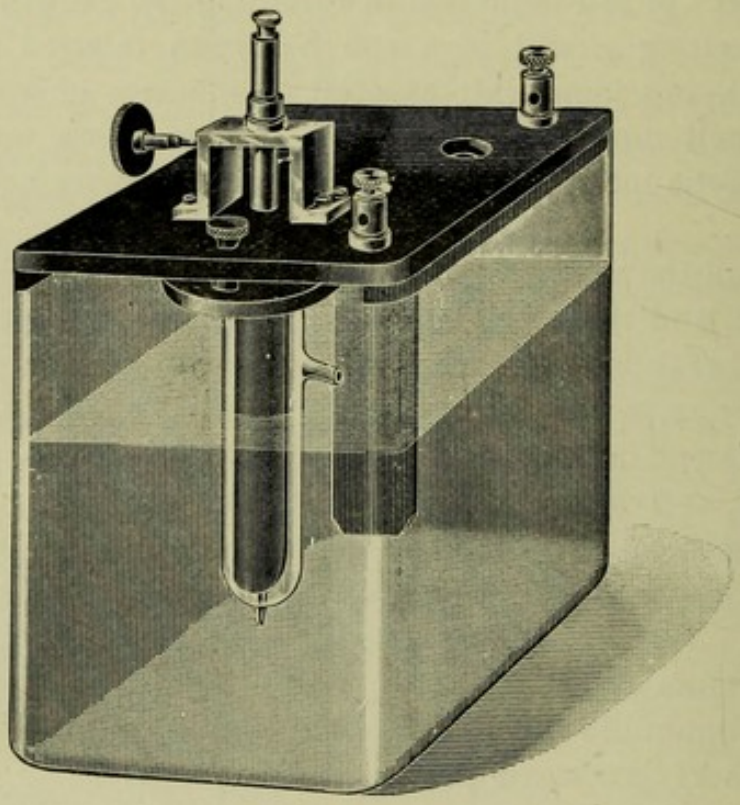


FIG. 119.—CALDWELL'S ELECTROLYTIC INTERRUPTER.

which is accordingly provided with an overflow channel through which the liquid returns into the outer vessel. As both poles are of lead and of large area, there is no special need to make the connections in one particular way as required for Wehnelt's form.

In the Caldwell Swinton interrupter the size of the hole in the partition is varied in the following way: The inner vessel has a small hole about 3 or 4 millimetres in diameter at its lower end. Into this hole projects the tapering end of a glass rod, which is attached to an adjustable screw, so that it can be raised or lowered as required. In this way the aperture can be partially

closed by altering the position of the rod, and by this procedure the rate of the interruptions can be varied (Fig. 119).

With these electrolytic interrupters the appearance of the discharge of a coil is considerably altered. The sparks at the secondary terminals follow one another so rapidly as to give the appearance of torrents of sparks passing simultaneously; and with pressures approaching 100 volts, and adjustment for the highest rate of interruption, the discharge has the form of a sinuous arc of pale yellowish-green flame. For use with X-ray tubes it is best not to drive the rate of interruption too high, as few tubes will stand the strain. The higher the pressure the more rapid is the frequency of the discharge, and if it is tried to reduce the frequency by increasing the exposed area of the platinum at the anode, the current is likely to reach excessive magnitudes. To get the best work from an electrolytic break, it should be worked at as low a voltage as can be arranged to suit the tubes and coil employed.

113. **Practical Note.** — The account just given of Ruhmkorff coils and interrupters may leave the reader in some doubt as to the choice of an outfit best suited to his requirements. With regard to interrupters, the platinum break or hammer interrupter has the advantage of simplicity and of portability, when the induction coil is to be operated from a few accumulator cells, as at a patient's bedside. It is also useful as a reserve in case the other interrupters should fail; but in all other respects it is greatly inferior to the mechanical breaks. The best of these are the turbine breaks, with revolving contacts or revolving jet, the latter being the simplest. If enclosed in iron vessels they are so much the better. The rotary break of Mackenzie-Davidson is also a favourite interrupter, but it is only suited for use with accumulators or from the mains through a shunt circuit. The turbine breaks may be safely operated up to 250 volts, without the need for any shunt circuit for reducing the pressure, if care be taken to adjust them before starting, and a good series resistance be kept in circuit; but with pressures of 200 volts and upwards, the strain upon any interrupting device becomes a serious one, and the use of a shunt-resistance apparatus may be preferred in spite of its waste of current. The Caldwell break, however, works best at these extra high pressures, and consumes but little current. The chief difficulty with this interrupter is in the main-

tenance of the integrity of the perforated diaphragm. Porcelain is found to withstand the wear and tear fairly well, and it is possible that the Caldwell break in a perfected form may become a favourite now that pressures of 200 volts and upwards are so commonly used for electric lighting. In working on 200 volts with a Caldwell break, it is wise to use slender fuse wires in the circuit, so that they may easily rupture in case of short circuit from accident to the inner vessel or the diaphragm.

The Wehnelt interrupter is at its best at pressures between 60 to 90 volts, and should be regulated by means of a shunt circuit. When once adjusted to suit the coil it needs little attention, and can be kept in a cellar or other place remote from the consulting-room.

Coils which are fitted with a hammer-break should be provided with a separate pair of terminals for attachment to motor-driven interrupters. To connect up the latter a pair of wires is led from these terminals to the terminals of the interrupter, and the contacts at the hammer are separated by a piece of wood or cork wedged firmly between them. The wires from the battery or the main are joined to the coil as before. The same result is attained by removing the head of the hammer, the other platinum contact being withdrawn by a few turns of its screw. These modes of connection are adopted so as not to throw the condenser out of circuit.

For the electrolytic break the condenser is removed, and a different arrangement of connections is necessary. If the platinum contacts of the hammer are tightly screwed together, with no wood or cork between them, the electrolytic break can then be joined up in series with the source and the primary of the coil. If, as should be the case, a means of detaching the condenser is provided on the base-board of the coil, the mode of joining up the coil to the electrolytic interrupter is just the same as that employed with motor-driven breaks, but the condenser must also be detached by removing the connections on the base-board which are supplied for the purpose.

The capacity of the condenser also permits of alteration in a good induction coil, and a few experiments should be made to try the effect of varying its capacity to suit different conditions of working. If the condenser connections be so disposed as to allow of its being used to one-third, two-thirds, or the whole of its capacity, this will suffice for most medical purposes, as the

condenser is already roughly adjusted to suit the coil before the instrument leaves the makers.

With regard to the disposition of the primary windings, the simple arrangement of all the turns in series is the best for most purposes. This gives the highest self-induction, and so acts as a useful "choke" when the coil is driven from high pressures. It economises the expenditure of current, and reduces the severity of the sparking at the interrupter. Moreover, a high self-induction in the primary keeps down the electromotive force of the secondary waves at "make," and this is an advantage in X-ray work. If electrolytic breaks are used, the arrangement of the primary generally needs altering so as to reduce its self-induction, for otherwise, owing to the extreme rapidity of the interruptions, the "choking" effect of a high self-induction in the primary prevents the attainment of the full length of spark between the secondary terminals. To meet these conditions of working the arrangement of the primary is changed so as to reduce its windings, and this is done by cutting out one or more of its layers, or by connecting them in parallel instead of in series. Plugs or binding screws on the base-board are provided for making the change. Induction coils are made in box form for convenience of transportation to the bedside, and illustrations of these are given in the price lists of the instrument makers.

114. **The Operation of Ruhmkorff Coils from Electric Lighting (D.C.) Circuits.**—The gradual extension of electric lighting and of X-ray work has led to much inquiry as to the best way of working coils from electric light mains. In dealing with the question it is necessary to consider the circumstances under which the coil is to be used, and also the qualifications of the operator who is going to undertake the work. The apparatus which would be the best in skilled hands might not be so suitable for use by occasional and less experienced workers.

In a place supplied by direct current mains the possible modes of utilizing them are as follows :

1. Accumulators may be charged and then employed to operate the coil by means of a hammer interrupter and six or eight accumulator cells (12 to 16 volts). This arrangement is portable, but not nearly so good as the use of the Gaiffe jet break, which may be fitted for work at any pressure from 12 volts upwards, and is also quite portable.

2. Accumulators may be discarded, and the mains may be

employed to supply the coil direct through a shunt resistance, which permits of a wide range of pressure being employed. This plan is good when extra high-pressure mains (200 volts and upwards) have to be utilized, particularly when the coil is only used occasionally. A mercury jet break can be used very conveniently in this arrangement, and will be preferred unless much heavy work has to be done. In that case the Wehnelt interrupter in a large receptacle, such as a foot-bath or a bucket, will best meet the requirements of the case, though at a considerable expenditure of current.

3. In the hands of careful workers the mercury jet break may be used direct on the mains, without the need of a shunt resistance to reduce the pressure. By attention to details of speed of break and duration of contacts it is possible to obtain excellent results with this form of break, and the further control needed for regulation is obtained by the employment of a series resistance in the primary circuit. The amount of current consumed under these conditions need not be much more than 3 ampères for a 12-inch coil. It is fortunate that the jet break can still be used, although pressures below 200 volts have almost disappeared from public lighting circuits.

4. For pressures of 200 volts and upwards the use of a motor dynamo driven by the higher pressure and generating at 50, 60, or 100 volts offers certain advantages, and should be preferred wherever much work is to be done. Additional steadiness of supply is obtained if the field coils on the generating side of the machine are energized directly from the mains. The use of a motor dynamo permits of a certain degree of variation, for by a series resistance in circuit with the field magnet windings of the generator the working pressure can be made to range between 50 and 100 volts, to suit either the mercury jet break or the Wehnelt interrupter.

5. There is another mode of employing high-pressure mains for induction coils which has a theoretical interest, and that is to employ condensers which are charged from the mains and discharged through the primary coil by means of a two-way commutator. This plan, first described by Norton and Lawrence,* was developed by N. Tesla, whose apparatus is described in the *Electrical Review*† of the same year. As the

* *Electrical World*, New York, March 6, 1897.

† London, September 10, 1897.

discharges of a condenser through the primary of a coil are oscillatory, the discharges induced in the secondary are also oscillatory, and therefore are not exactly comparable with those produced by an induction coil excited in the ordinary way.

An improvement upon this idea consists in the excitation of the primary by the current charging the condensers instead of the discharging current. The advantage gained is that the charging current is a non-oscillatory one. The discharge of the condensers is effected by a short-circuiting device, the current not going through the primary coil.

The Grisson apparatus is a contrivance for the operation of coils from the electric light mains by this method. Condensers of large capacity (100 microfarads) are momentarily connected to the mains through the primary windings of the coil. The rush of current through the coil into the condensers comes to a natural termination when the condensers are charged to the full pressure of the mains, and if their connection with the mains is then broken, there will be no sparking at the point of interruption. The condensers are then discharged through a side circuit, after which they are ready to receive a fresh charge from the mains, sent into them through the primary of the coil as before. By means of a suitable designed commutator driven by a motor this cycle of events can be repeated in quick succession. An induction coil operated in this manner gives a magnificent discharge from its secondary terminals. The apparatus consists of a motor-driven commutator with massive sections, and the condensers are aluminium cells, as these afford a means of obtaining very large capacities in an economical manner (§ 98). A switch-board is supplied with the apparatus, as the connections are somewhat complicated. The instrument is still in process of improvement, and has not yet come into general use.

115. **The Alternating Current Mains.**—The direct application of the alternating mains to the excitation of coils is a more complicated matter.

If an induction coil is connected to a source of alternating current through an interrupter, the discharge of the secondary is irregular and unfit for use. This would not be the case if the interrupter were in step with the periodicity of the current, and worked so as to break the circuit at the right moment. Attempts have been made to bring about this result, and several

of the synchronous rectifiers described in the last chapter for use in the charging of accumulators from alternating mains can be adapted to work as synchronizing interrupters for coils. Of these instruments the Siemens' rectifier and that of Mr. Russell Wright have proved capable of good work (§ 97).

In all devices of the kind only one speed of interruption is possible—namely, the speed which keeps time with the periodicity of the supply. In this country this ranges for the most part between 40 and 100 periods per second, which is a satisfactory rate of interruption for an induction coil. Regulation of output can be effected easily in other ways, either by the use of a series resistance to control the current or by a transformer to control the pressure.

A form of the mercury jet interrupter is made for use on alternate current circuits. It resembles the pattern used on direct circuits, except that the motor driving it is a synchronous motor keeping step with the periodicity of the current. A hand-wheel is used to start the interrupter. Such a manœuvre is usually necessary with synchronous motors, as they are generally unable to start from rest, and must be artificially assisted to reach their proper speed, though when once in step they maintain a constant rate even under trying variations of their load.

Another method of adapting the alternating current mains for the operation of coils is to use the aluminium rectifier in one of its four-celled forms, as described in the preceding chapter. Though the current from this apparatus is pulsatory rather than strictly continuous, it has been successfully employed, both for driving a direct current motor to actuate the interrupter and for supplying the primary circuit of the coil.

It has been noticed that there is a certain natural tendency on the part of Wehnelt's electrolytic break to transmit the pulsations in one direction more readily than in the other, and with a little care and management this form of interrupter can be used with the alternating mains. Dr. Dujon* was one of the first to describe his results in this direction, and states that with a Wehnelt interrupter the discharge of his 14-inch spark coil was absolutely unidirectional, so that reversing the commutator of the coil had exactly the same effect as if he had been using a battery current. He mentions that the voltage of

* *Archives d'Électricité Médicale*, April, 1901, p. 214.

supply was 110, and the periodicity was 53 per second, and that the best results were given with the pressure reduced to 85 or 90 volts, with the ammeter reading between 4 and 10 ampères. Graduation was effected by adjusting the amount of exposed platinum in the interrupter.

Messrs. Gaiffe have constructed a special form of electrolytic break to work on alternating circuits. They advise careful adjustment of the platinum anode at the commencement, and their apparatus insures constancy of action for a considerable period of time by the following simple device : The projecting platinum pin rests at its point upon a plate of mica, which is fixed just beneath, and as the point wears away the platinum rod slips down by its own weight, and so the original length of the exposed portion is preserved. The apparatus is noisy in action, and there is a good deal of wear and tear of platinum, very much more than is the case when Wehnelt's interrupter is used with direct current.

With pressures up to 110 volts the ordinary forms of Wehnelt interrupter may be used if arranged in series with a single cell of the aluminium rectifier, and this can easily be constructed at home by anyone with a taste for mechanical work. It is possible that the simplification of the apparatus might be taken a step further by combining the rectifier and the Wehnelt break in one vessel. To do this the electrolyte of sulphuric acid should be replaced by one of ammonium phosphate, and an aluminium rod substituted for the lead plate forming the negative pole.

To make this device successful a large volume of electrolyte would be necessary, as the heat generated in an electrolytic interrupter is considerable, and the valve effect of the aluminium cell falls off at 40° C. A surface of a few square inches of aluminium is sufficient for fairly large currents, as the valve effect is best when the current density at the surface of the aluminium is moderately high.

The choice among these methods of employing alternating mains will depend upon the worker. For least expense, the use of the aluminium valve for charging accumulators, and the working of the coil from these with the Gaiffe jet break or the Mackenzie-Davidson interrupter is perhaps the best.

The methods of utilizing alternating mains which have just been enumerated are methods for adapting that type of current to direct current types of apparatus, and are of the nature of

makeshift contrivances. The natural way of utilizing alternating circuits would seem to lie in the direction of step-up transformers capable of providing the necessary voltage as a substitute for the induction coil. This tempting short-cut has attracted investigators for some time, but the practical difficulties of the method have prevented the realization of the idea until recently. Villard, in 1899, had already advanced the matter very notably by his device of a valve tube, and by suggesting the employment of condensers of small capacity to limit the output of the transformer when this was desirable. Other obstacles of no small magnitude arose from the very high electromotive forces required, and the difficulty of constructing a transformer which could provide such a pressure without breaking down was for a time insuperable.

The experience gained in the manufacture of large coils during recent years has prepared the way for the successful construction of transformers capable of providing pressures up to 100,000 volts, and the use of these instruments will be considered in a succeeding paragraph.

116. **The Spark-discharge of a Ruhmkorff Coil.**—Those who are interested in the phenomena of the discharges of the induction coil should consult M. H. Armagnat's book,* which contains much valuable information, both practical and mathematical, on all points connected with large coils. The spark-discharge of a coil usually takes the form of bright crackling flashes. If the terminals are a little too widely separated for the sparks to leap across, then violet brush discharges occur from the rods of the dischargers and from the conductors which join them to the terminals of the coil. On reducing the distance separating the discharging terminals, the ordinary bright zigzag sparks make their appearance, and as the distance is further reduced the sparks appear to become thicker, and to consist of a central bright part surrounded by a fainter reddish aureole. On bringing the terminals still closer together, one obtains a thick yellow curved or sinuous flame, which is hot enough to set fire to a piece of paper, and is kept in a state of upward movement by the currents of air produced by its high temperature. Armagnat points out that the sparks with aureole are really groups of sparks, the first being bright, and the others fainter and redder, as they represent the residual energy of the discharge impulse, which is

* *La Bobine d'Induction*, par H. Armagnat, Paris, Gauthier-Villars, 1905.

enabled to leap across along the line of heated air left by the first spark. The yellow thick flame discharge admits of a similar explanation, but is made up of a greater number of discharges. To obtain the longest sparks from a coil the discharges should take place between a point and a disc, and the point should be positive. Under these circumstances the sparks strike the disc

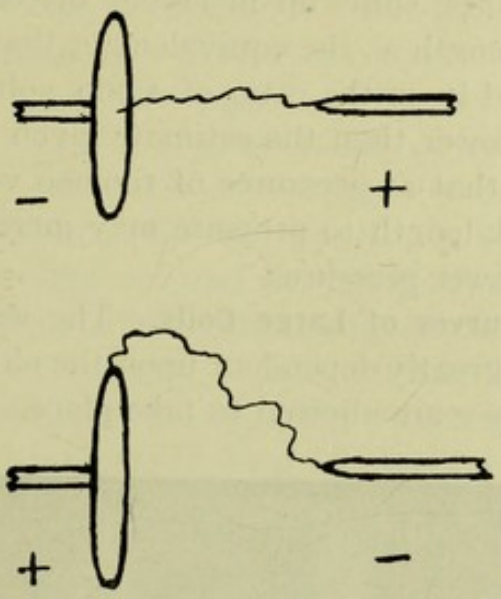


FIG. 120.—SPARK DISCHARGES BETWEEN A DISC AND A POINT. (AFTER ARMAGNAT.)

upon its face, and not upon its edge. If the current be in the opposite direction the sparks are shorter, and take a curved path, striking only upon the edge of the disc (Fig. 120). This difference of behaviour affords a simple way of recognising the polarity of the terminals of a coil.

117. **Sparking-distances at High Potentials.**—It is difficult to do more than guess at the potential difference required to produce a given length of spark in air. Many measurements have been made by different observers, but their results vary widely. The forms of the terminals between which the discharge takes place have a considerable influence upon its length, and the figures obtained in any given set of experiments seem to depend a good deal upon whether the terminals employed were plates, balls, points, or combinations of these. The uncertainties which surround the problem are quite natural, because the measurement of electromotive forces becomes increasingly difficult as the pressures rise higher and higher, and the stage at which a discharge changes from brush to spark is not always easy to

determine. Fleming* writes that for sparks having lengths up to five or six centimetres we shall generally not be wrong in reckoning the voltage required to produce a spark between metal balls in air at the ordinary pressure as 3,000 volts per millimetre.

Bergonié,† in discussing the probable spark-length corresponding to 100,000 volts, sums up in favour of regarding 10 centimetres of spark-length as the equivalent of that potential difference. This would be in the ratio of 1,000 volts per millimetre, and is therefore lower than the estimate given by Fleming; but it is quite likely that at pressures of 100,000 volts and upwards the ratio of spark-length to pressure may increase more rapidly than it does at lower pressures.

118. **Current-curves of Large Coils.**—The waves of discharge of large coils are greatly dependent upon the nature of the circuit through which they are allowed to take place. When a coil dis-

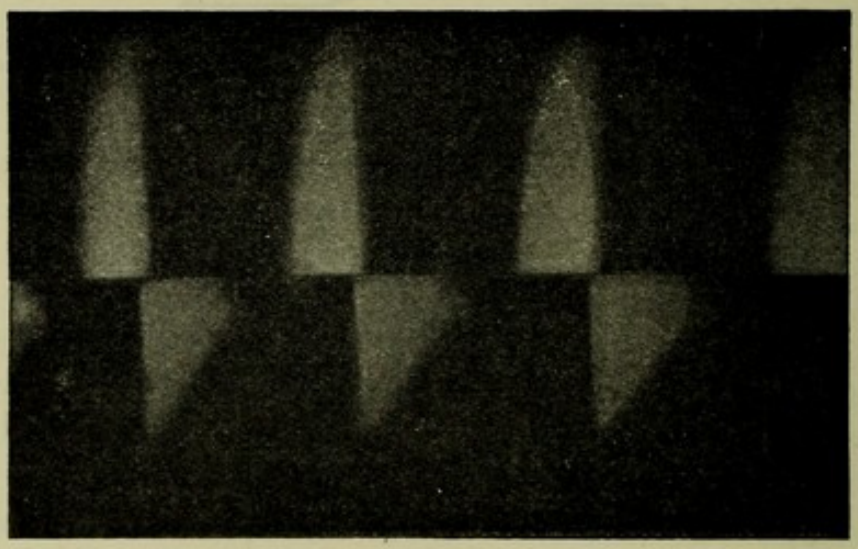


FIG. 121.—CURRENT CURVE OF RUHMKORFF COIL.

charge takes the form of sparks in air these have a very short duration, but when the discharge passes through a vacuum tube it may have the character of long waves resembling those illustrated in § 61 for small medical coils. Of those figures, the one whose contours most resemble the discharges of a large Ruhmkorff coil is Fig. 36, because the great length of the windings and the mass of the iron core of a large coil conduce to the production of long waves, which have not time to reach their close before

* *Cantor Lectures, p. ocit.*, p. 31.

† In Bouchard's *Traité de Radiologie Médicale*, p. 158.

the re-establishment of the next wave in the reverse direction. The waves at make in the secondary of a Ruhmkorff coil will also be larger, and will approximate more to those at break, in proportion as the electromotive force applied to the primary circuit is higher. In some photographs of the discharges of large coils given by E. Ruhmer,* these characters are well seen, and one of his illustrations is reproduced here (Fig. 121).

119. **The Oscilloscope.**—Under the name of the glow-light oscillograph Ruhmer† has suggested the use of a special form of vacuum tube (Fig. 122) as a means of observing the wave contours of high potential discharges. It is based upon an adaptation of the fact observed by H. A. Wilson,‡ that in a vacuum tube the area covered by the glow upon the negative wire is proportional to the magnitude of the current through the tube. When a suitably exhausted tube is traversed by a high potential discharge the negative wire is partly covered by a violet glow, which seems to form a luminous sheath to the end of the wire, and extends along it for a certain distance. With increase of current the glow extends along the wire, and with decrease of current it becomes shorter. If the current is alternating in direction, and unequal in amount, as in the case with induction-coil discharges, then both wires show the negative glow to an unequal degree. To the eye the glow appears steady, but when viewed in a revolving mirror it is found to rise and fall in time with the interrupter, and so to trace out the contours of the wave-impulses of which the discharge of the induction coil consists.

This simple instrument is described here because it may be used to obtain valuable information as to the behaviour of induction coils. By its means the character of the discharge under different conditions can be examined. For instance, it can be used to examine the working of the interrupter of the coil, the nature of the current through an X-ray tube, or the degree of efficiency of rectifying devices. The appearances as seen in the revolving mirror are of great beauty. It serves better as an oscilloscope than as an oscillograph, although photographs can be taken by the device of driving the mirror synchronously, as has been shown by Ruhmer. In judging the appearances

* *Elektrotecknische Zeitschrift*, February 9, 1905.

† *Ibid.*

‡ *Phil. Mag.*, November, 1902, p. 608.

observed in the mirror, it is necessary to remember that the glow upon the wire is not a mathematical line, but has a certain thickness, and, in addition, that it has a peculiar "test-tube" shape, for which reasons the curves seen in the mirror present a certain degree of distortion, which, however, is not sufficient to interfere with the value of the apparatus for qualitative purposes.

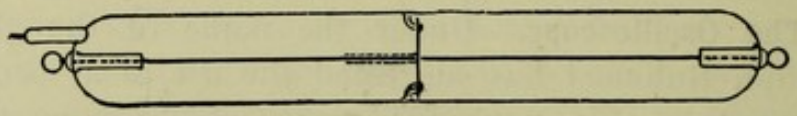


FIG. 122.—VACUUM TUBE OSCILLOGRAPH.

Ruhmer's tube is 35 centimetres long and 4 centimetres in diameter, with two rigid nickel wires arranged axially. The interval separating their ends is very short—viz., about 2 millimetres—and a disc of thin porcelain or mica is fixed at this point. It is pierced by a small hole, which corresponds with the ends of the electrodes. The vacuum is about 6 millimetres of mercury.

120. **High Potential Transformers.**—The great convenience attending the working of large coils directly from the con-

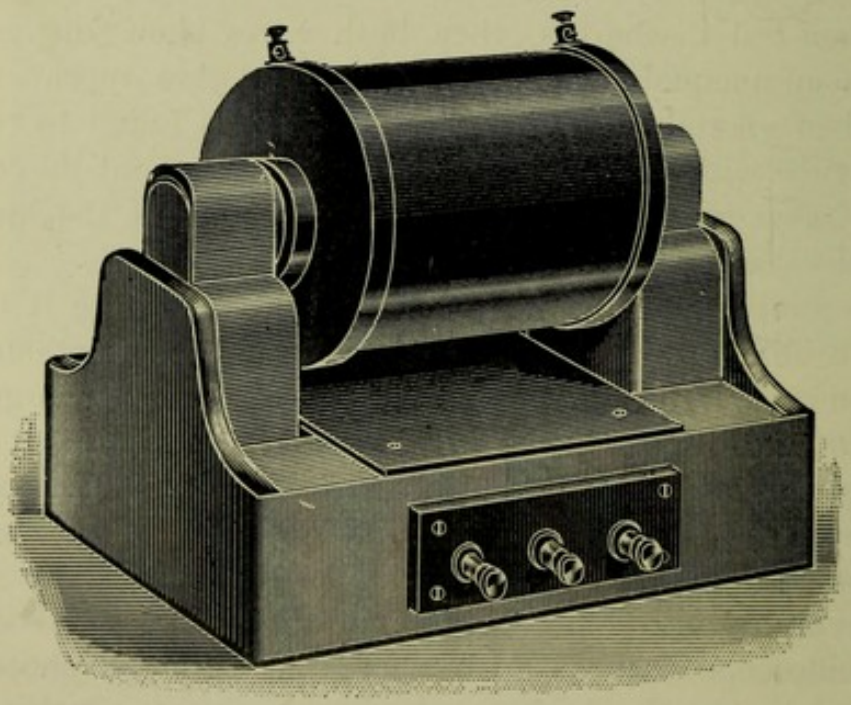


FIG. 123.—100,000-VOLT TRANSFORMER WITH CLOSED IRON CIRCUIT.

tinuous current mains, and the difficulties of doing the same thing in places supplied by alternating current, has led to many attempts to devise a satisfactory method of utilizing alternating

currents in a similar way. Further, the improvement in the manufacture of large coils, which has resulted from the general demand for that form of apparatus, has led to similar improvements in the construction of high potential transformers, and these can now be obtained to give 100,000 volts at about the same price as coils of the same order of magnitude. Fig. 123 shows one of these instruments constructed by Mr. Leslie Miller

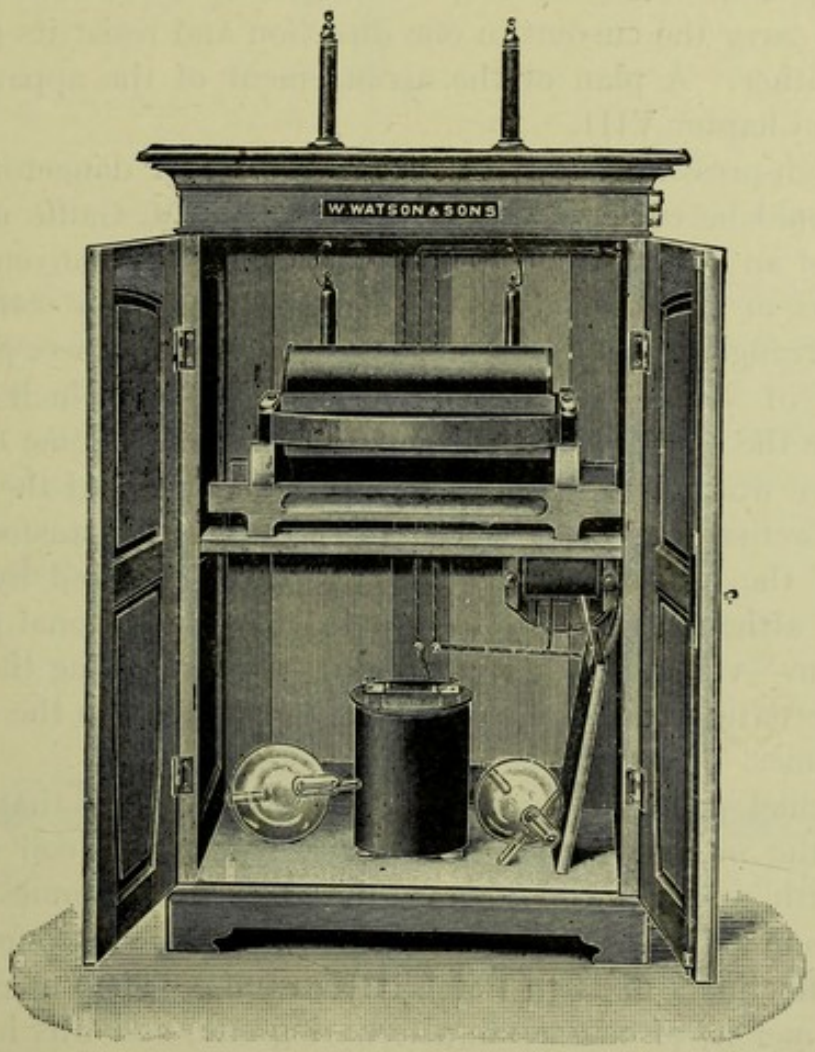


FIG. 124.—HIGH-PRESSURE TRANSFORMER IN CABINET, WITH ALUMINIUM VALVE CELL IN TERTIARY CIRCUIT.

on the same lines as the jointless section soils (§ 108). Several other makers of electrical apparatus also supply high-potential transformers for medical applications. One of the first constructors to introduce high-pressure transformers for these purposes was M. Gaiffe, who for several years has manufactured a transformer equipment specially arranged for X-ray and high-frequency work. In that apparatus the high-pressure side of

the step-up transformer is shunted by four condensers in series to one another, and these are called guard condensers. It is probable that their action may be partly protective and partly of the nature of a resonance device. Each lead then passes through an electrolytic cell of special construction, and then to another pair of condensers. On the further sides of these condensers are the discharging terminals, and for use in X-ray work a pair of valve tubes are arranged in series across them, so as to carry the current in one direction and resist its passage in the other. A plan of the arrangement of the apparatus is given in Chapter VIII.

All high-pressure transformers are somewhat dangerous, and they should be enclosed in locked cabinets. M. Gaiffe uses the device of an automatic switch which cuts off the current when the doors of the cabinet are opened and is a very convenient safety arrangement. These high-pressure transformers give out streams of sparks ten or twelve inches long, which closely resemble the sparks from a large induction coil. Some of those who have worked with a transformer apparatus find the results so satisfactory that they advocate the use of a transformer in place of the Ruhmkorff coil even in places supplied by direct current, although this involves the use of an additional piece of apparatus—viz., a motor transformer—for converting the direct into alternating current before it can be supplied to the step-up transformer.

The chief point in favour of the transformer is that by its means the interrupter required for a Ruhmkorff coil is done away with, and as a consequence the apparatus becomes almost noiseless in action. Measurements of current are also simplified.

121. **Rectifiers of High Potential Currents.**—The current of a transformer is, of course, an alternating one, and this has been an obstacle to the application of transformers to X-ray work. In 1899 M. Villard invented an ingenious rectifying device or valve tube for correcting this difficulty. It consists of a vacuum tube in which one terminal is enclosed in a narrowly-constricted portion of the tube, while the other is suspended freely in a wide portion (Fig. 125). A tube of this kind will transmit current easily when the helix is the kathode ; but when the current is in the opposite direction it transmits little or none. These valve tubes can be used in either of two ways—viz., arranged in series with the apparatus so as to arrest the impulses tending to traverse

it in the one direction, while providing a free passage for the impulses in the other; or else being placed in shunt to the apparatus so as to carry off the wrong impulses, while resisting

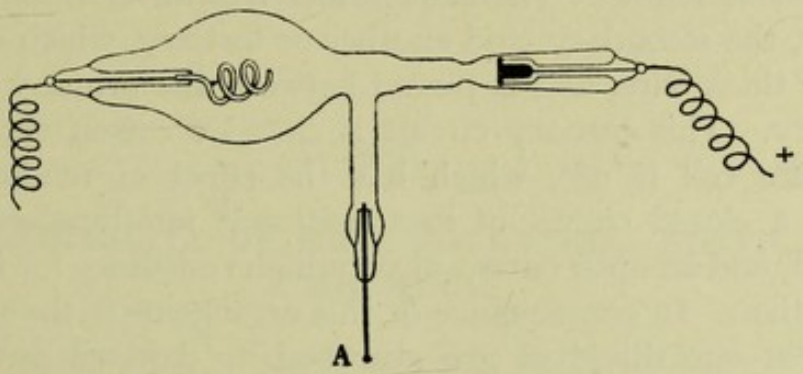


FIG. 125.—VALVE TUBE OF VILLARD WITH VACUUM REGULATOR (A).

the others, and so compelling them to traverse the desired path. In another form of valve tube introduced by Watson and Sons (Fig. 126) one of the electrodes is a concave disc of aluminium, and the other is a bare metal cylinder with an expanded or trumpet-shaped extremity. In this type of tube the current passes freely when the concave disc is made the positive pole, but passes hardly at all in the opposite direction.

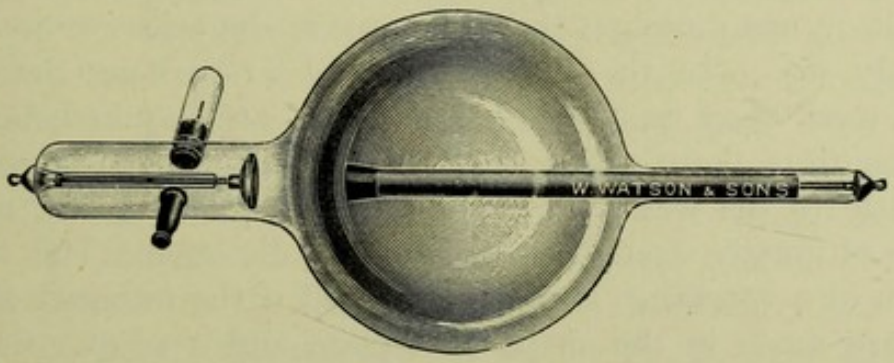


FIG. 126.—VALVE TUBE OF J. KOCH.

Another way of getting rid of the semi-phases of current which are in the wrong direction is the synchronously revolving commutator which has been devised by J. Koch. It consists of a pair of rotating arms driven by a motor supplied by the alternating current which feeds the transformer, and it is so arranged that in its rotation it collects the appropriate impulses from the terminals of the high-potential transformer, and conveys them to the circuit of the X-ray tube. The appearance of a tube operated from this device is sharp and good.

J. Koch has also devised another extremely ingenious method of suppressing one set of impulses, so as to obtain unidirectional currents from a high-potential transformer. The method is as follows : The transformer has three windings—the primary, the secondary, and another or tertiary, which is of few turns of thick wire, and is placed between the primary and the secondary. This tertiary circuit is closed on itself through an aluminium cell (§ 98), which has the effect of rendering the tertiary a closed circuit of low resistance for impulses in one direction, and an open circuit of very high resistance for impulses in the other. In consequence of this arrangement the pulses of current in one direction are absorbed or damped out in the tertiary, while those in the opposite direction are utilized for the generation of a high electromotive force in the secondary, and the discharges of the secondary are thereby rendered unidirectional.

Sir Oliver Lodge has recently advocated the use of mercury vapour lamps as rectifiers of high-potential currents.*

Although the principle of rectification has its most important applications in the case of transformers, it may also be useful in some cases with induction coils. The current of a coil is alternating in direction, though the electromotive forces are much greater in one direction than they are in the other, as we have already seen. In the case of the coil a spark-gap has long been used when unidirectional impulses are required, because the length of the spark-gap can be so adjusted as to present an obstacle to the waves of low electromotive force, but not to those of greater strength in the reverse direction. This sifting action of a spark-gap is much enhanced if the terminals of the gap are made in the shape of a plate and a point. Current crosses such a gap best when the point is positive, as we have seen in a preceding paragraph for X-ray purposes. The use of a valve-tube rectifier arranged in series in the secondary circuit of an induction coil improves the working.

* See the *Electrician*, January, 1905.

CHAPTER VI

ELECTRICITY OF HIGH POTENTIAL—STATICAL MACHINES

Historical—Description of instruments—The Holtz machine—Wimshurst's machine—Conductors and electrodes—Treatment by charging—The static breeze—Treatment by sparks—The Leyden jar—Morton's method.

122. **Electrostatic Machines.**—The use of electrostatic machines for medical purposes is of historic interest, for it dates back to the dawn of the science of electricity.

De Haen (1745), Jallabert (1748), and the Abbé Nollet (1749), were the first to apply statical electricity to medicine.

In 1758 Benjamin Franklin relates that in consequence of the cures reported to have been made in Italy and Germany, a number of paralytics were brought to him for treatment from various parts of Pennsylvania and the neighbouring provinces.

In 1759 the Rev. John Wesley, the famous divine, collected a number of cases in which electricity had been tried, and published a treatise entitled 'The Desideratum, or Electricity made Plain and Useful, by a Lover of Mankind and Common Sense.' In this are given the details of a vast number of cases treated by electricity. Among them he mentions that electricity accelerates the passage of calculi through the ureters. He also relieved tertian and quartan fevers and hysteria.

In 1777 Cavallo published in London a complete treatise on electricity in theory and practice, with original experiments. It included general remarks relating to Medical Electricity.

The first form of electrical machine was a large sulphur ball, which was excited by the friction of one hand as it was revolved by the other. It was made by Otto von Guericke of Magdeburg in 1672. Subsequently resin, and then a glass cylinder, were used, instead of the sulphur ball, and in 1740 horsehair cushions covered with silk were used instead of the hands for producing the friction.

Some interesting reproductions of old figures of early electrical machines are given by Dr. Mount Bleyer of New York in Bigelow's "System of Electro-Therapeutics."

In 1760 Ramsden substituted a circular glass plate for the cylinder, and his apparatus was, until recently, in common use.

In modern machines induction is utilized for producing the electrical separation, and on this account they are often known as influence or induction machines. In 1865 Holtz of Berlin invented a machine which, when once charged, would continue to produce electrical separation by induction. It proved to be far superior to the older frictional machines, and quickly supplanted them in spite of certain drawbacks. In its original form it required to be excited from an outside source before it could begin to work, it was liable to lose its excitation if worked upon open circuit, and it had a tendency to reverse its polarity during action; but from its good qualities it has been made the object of much attention, and has been much improved by the instrument makers of the United States, where the Holtz machine is in general use for therapeutic purposes.

123. **The Holtz Machine.**—In its simplest form it consists of two plates of glass, A. B (Fig. 127), one having a diameter slightly greater than the other. The larger plate is fixed, but the smaller one rotates. The plates are close together, but do not touch. In the fixed plate are two openings or "windows," *a*, *b*, diametrically opposite to each other. Two pieces of paper called "field plates" are glued on to the fixed plate, one above the window on the left side, and one below the window on the right. They are on the surface of the plate away from the revolving one. A tongue from each of these pieces of paper protrudes through each aperture, and nearly touches the revolving plate. The plate is rotated in an opposite direction to that in which the tongues point. Two metallic combs, *g*, *i*, supported by brass rods with knobs, *f*, and mounted on glass supports, form the prime conductor. Two smaller brass rods, with ebonite handles, and knobs act as discharging electrodes, by means of which the length of spark can be regulated. The rod, *t v*, is called the neutralizing rod, and is said to make the machine less likely to reverse its polarity when working. Before starting the machine, one of the field plates must be charged from an outside source, and the knobs of the discharging rods are to be brought together. The movable plate is then

rotated rapidly, and a series of sparks will pass between the electrodes.

In the modern machines used in electro-therapeutics there are many modifications in details. First, the machine has four, six, or eight pairs of plates, and is enclosed in an air-tight case. The fixed plates are no longer circular, with windows and a hole for the axle, but for the sake of simplicity of manufacture they are oblong, and are held in place by grooves in the framework of the case, and each is made in two pieces which do not quite

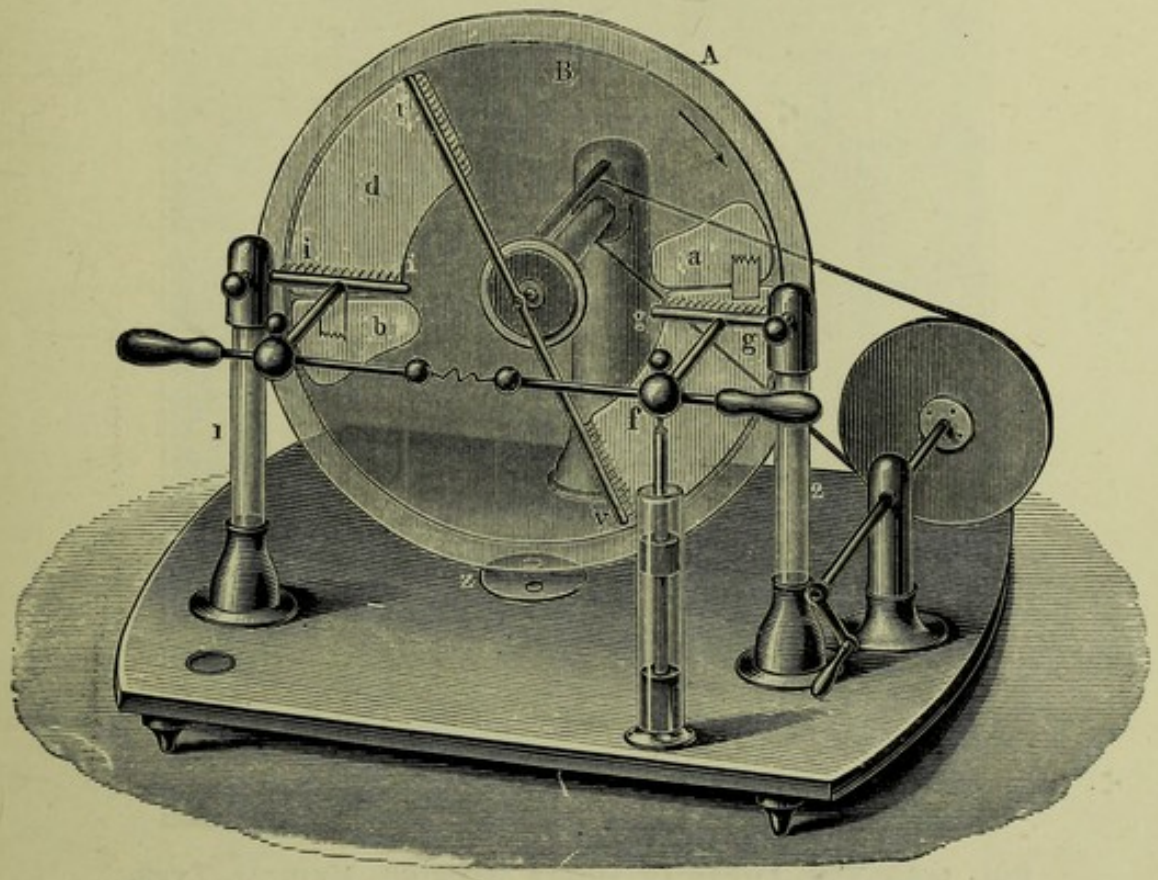


FIG. 127.—HOLTZ MACHINE.

touch each other, and so leave room for the axle to revolve between them. The "field plates" of paper are glued to the fixed plates on the side which faces the rotating plate or near side, instead of being on the opposite or far side. This prevents the reversals of polarity during action, which occurred with the original Holtz machine, by preventing the formation of an accumulated charge of opposite sign on the near side of the fixed plate, as used to be the case when the field plate was attached on the far side.

Machines for electro-therapeutics usually have revolving plates

thirty inches in diameter, and are generally driven by an electric motor. For providing the initial charge which is required to

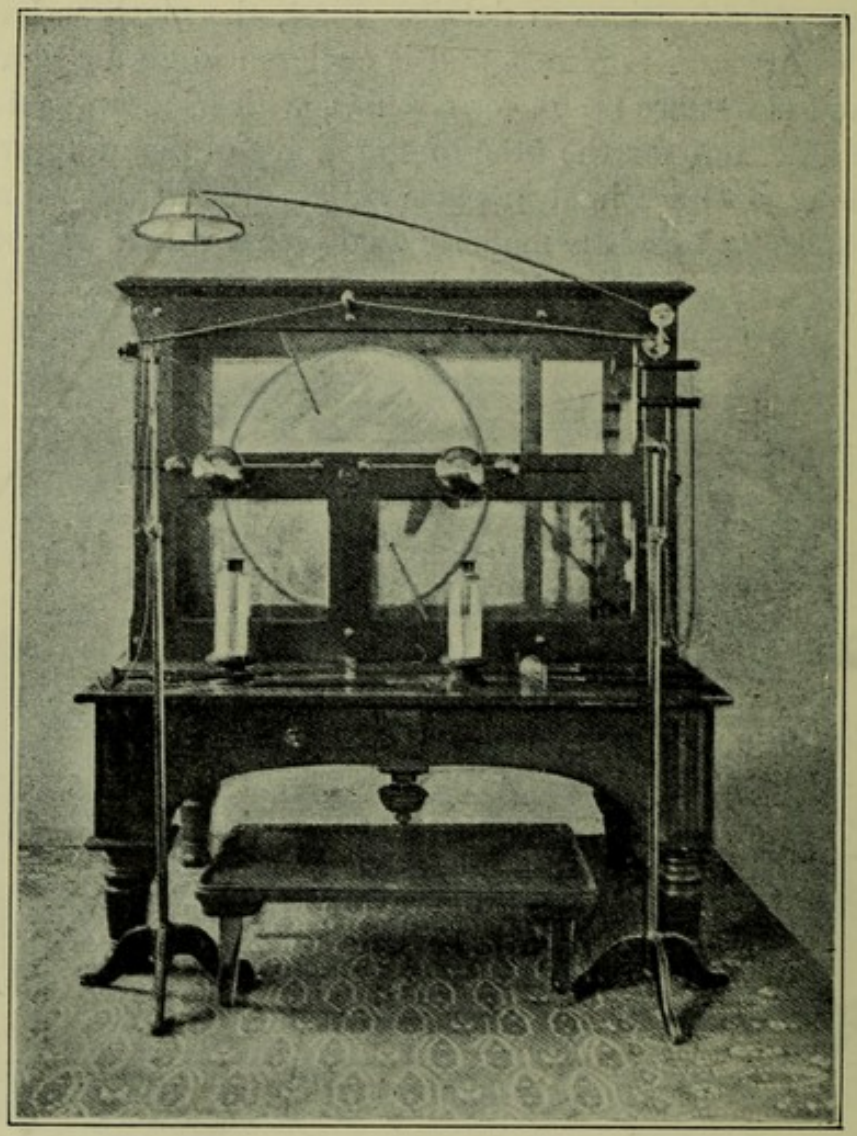


FIG. 128.—THE AMERICAN HOLTZ MACHINE, MEDICAL TYPE.
(WAITE AND BARTLETT MANF. CO., NEW YORK.)

excite the action of the machine, a small Wimshurst or Voss machine is fitted in the corner of the case of the instrument.

124. **The Voss or Toepler Machine** is also used directly as a medical static machine. It is more nearly a self-exciting machine than the Holtz, but, like that form, it is less sure in its action than the Wimshurst machine.

The Voss machine resembles the Holtz in a general way, but the moving plates carry a few sectors, and these in their rotation touch a pair of brushes which are carried by two bent arms which

connect with the field plates and so convey charges from the moving plate to the armature of the fixed field plates.

The Wagener mica plate machine is a modified Voss machine, in which the moving plates are made of a compound of mica and shellac. They are light, and can be safely driven at a high speed.

125.—**The Wimshurst Machine.**—The Wimshurst machine has the advantage over the Holtz that it is self-exciting, and its polarity will not reverse under ordinary circumstances while it

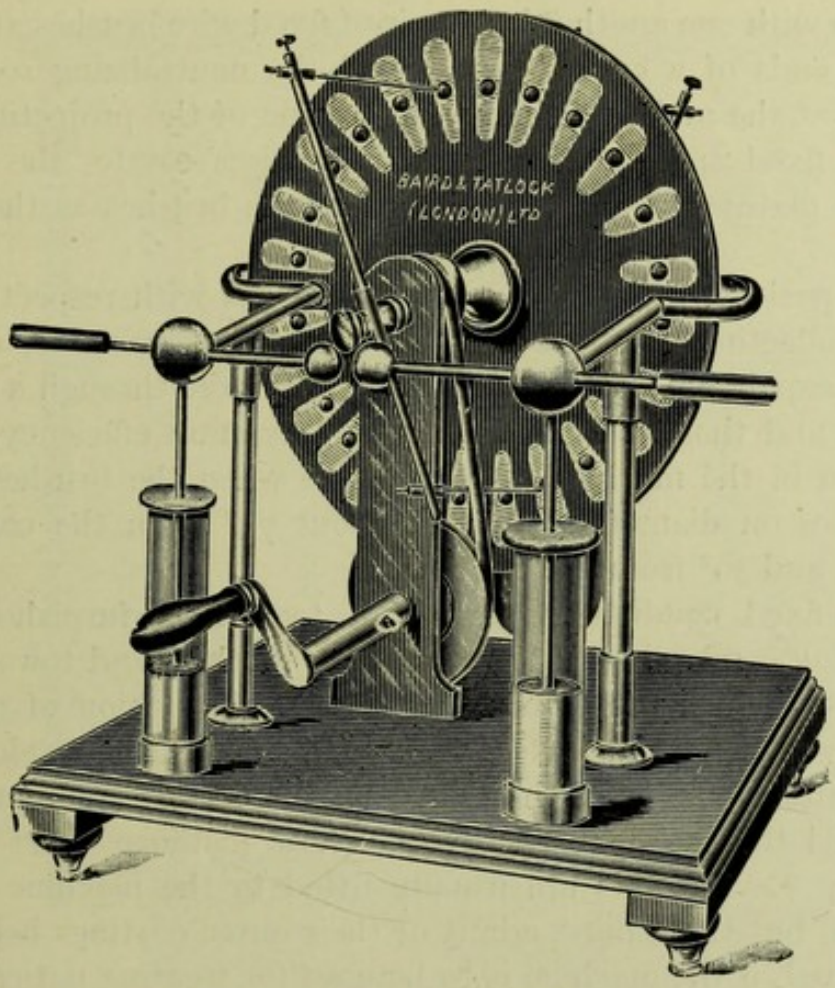


FIG. 129.—WIMSHURST MACHINE.

is in action. It consists of two circular glass discs (or any even number up to twelve), mounted in pairs upon a fixed horizontal spindle in such a way that they rotate in opposite directions at a distance apart of not more than a fraction of an inch. Each disc is attached to the end of a hollow boss of wood, or of metal, upon which is turned a small pulley. The pulleys are driven by a cord or belt from larger pulleys attached to a spindle below the machine, and rotated by a winch handle or by a motor, the

difference in the direction of rotation of the discs being obtained by crossing the alternate belts.

Both discs are well varnished, and attached to the outer surface of each there are radial sector-shaped plates of tin-foil or thin brass disposed around the discs at equal angular distances. These sectors are not essential to the action of the machine, but they make it more easily self-exciting.

Twice in each revolution the two sectors situated on the same diameter of each disc are momentarily placed in metallic connection with one another by a pair of fixed wire brushes attached to the ends of a curved rod, called the neutralizing rod, supported at the middle of its length by one of the projecting ends of the fixed spindle upon which the discs rotate, the sector-shaped plates just grazing the tips of the brushes as they pass them.

The position of the two pairs of brushes with respect to the fixed collecting combs and to one another is variable, as each pair is capable of being rotated on the spindle through a certain angle ; and there is one position of maximum efficiency. This position in the machine appears to be when the brushes touch the discs on diameters situated about 75° from the collecting combs, and 30° from one another.

The fixed conductors consist of two forks furnished with collecting combs directed towards one another, and towards the two discs which rotate between them, the position of the two forks, which are supported on ebonite pillars, being along the horizontal diameter of the disc. To these fixed conductors are attached the terminal electrodes, whose distance apart can be varied. Leyden jars are usually fitted to the machine by the makers, but these must admit of their outer coatings being disconnected, if the machine is to be used for treating patients.

The machine is very efficient and perfectly self-exciting, provided there are sufficient sectors, generally requiring neither friction nor outside electrification to start it, and this is one of the most remarkable features of the apparatus, for under ordinary conditions the machine works at its full power after the second or third revolution of the handle. It has been suggested that the initial charge is obtained from the friction of the air, and that chiefly between the plates, but nothing certain is known about it.

The mode of action of a Wimshurst's influence machine is

not easy to explain in a few words. The following extract from a paper by Mr. Pidgeon* gives a general notion of the occurrences which take place when the machine is in action :—"If we follow the action of any single sector on a disc of one of these machines, we find it goes through the following electrical changes. Suppose it to be just leaving the positive collector, it comes into a strong positive field produced by the other disc, and while in

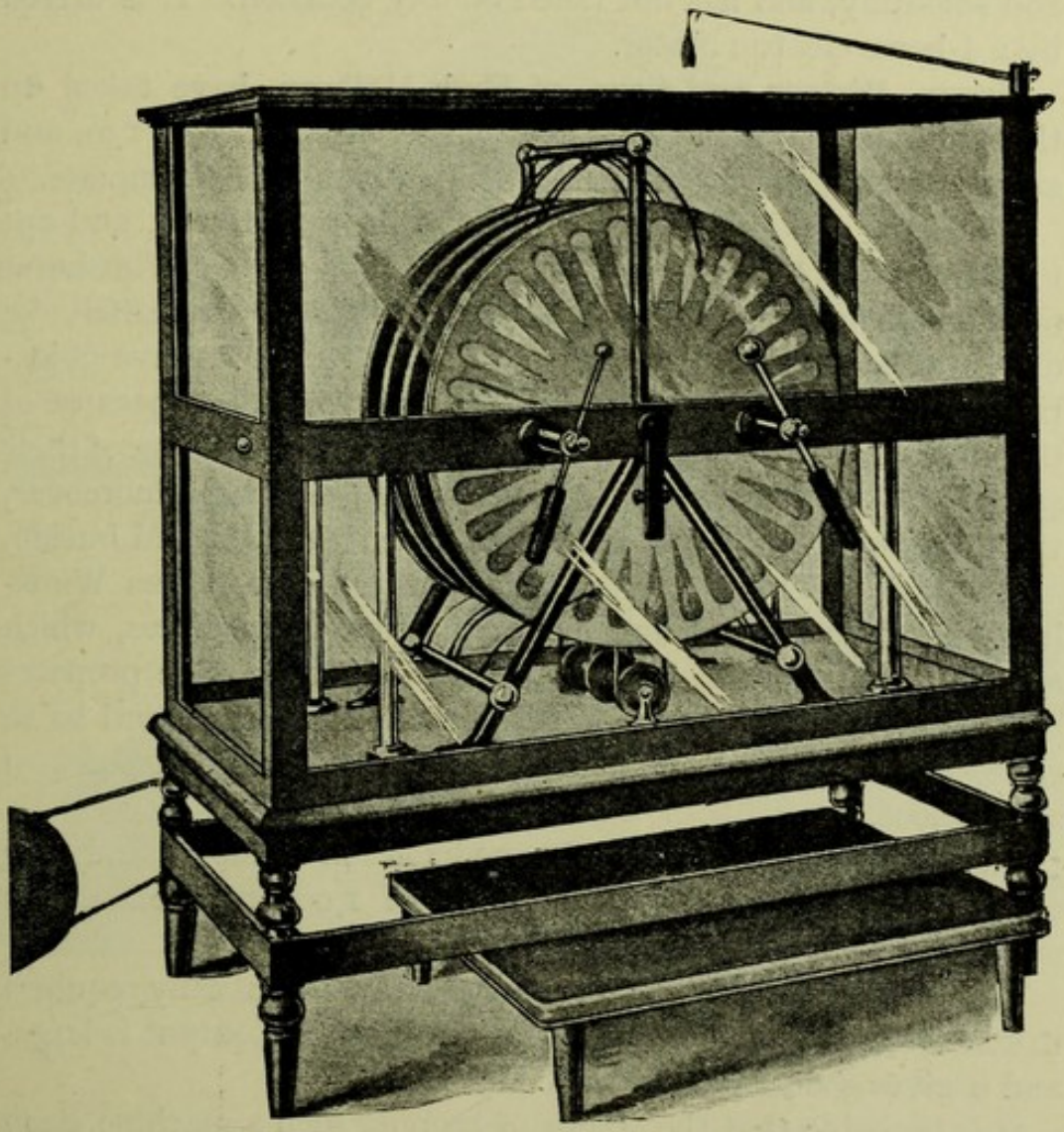


FIG. 130.—WIMSHURST MACHINE.

this field is earthed by the first neutralizing brush, and becomes charged negatively."

The Wimshurst machine is at its best when the resistance of the discharging circuit is very high, and the opposite condition of a free discharge in the outside circuit suits the Holtz type of machine best.

* W. R. Pidgeon, 'An Influence Machine,' *Phil. Mag.*, September, 1893.

A Wimshurst machine for therapeutic work should have eight plates of thirty or thirty-six inches diameter. Fig. 130 shows a machine built for the writer by Mr. C. L. Schwind, of Broomfield, near Derby. This machine, without any Leyden jars, gives streams of sparks ten inches long. It is enclosed in a roomy case to prevent waste by leakage from the machine to the case, and to protect it from damp and from dust. It runs silently and smoothly, and has not failed on any occasion. It is driven by a $\frac{1}{4}$-horse electric motor.

Messrs. Watson and Sons, of High Holborn, have taken up the manufacture of the type of machine shown in Fig. 130, and are prepared to supply an outfit with all accessories complete.

When the glass plates are very large they are heavy, and apt to crack. On this account a modification of the Wimshurst machine is made with ebonite plates. These may safely be driven at a very high speed. There is, however, a grave objection to the use of ebonite plates in expensive machines, because of their tendency to deterioration through a chemical change of their surface, by which they lose their insulating properties; moreover, the plates of ebonite cannot be kept true, but bend and buckle.

M. Gaiffe of Paris has lately introduced a sectorless Wimshurst machine, with a simple attachment of the plates, which makes it very easy to remove them for cleaning. He proposes by this means to do away with the need for a case, and so to cheapen its cost and make it more accessible for purposes of adjustment.

The plates are of stout ebonite, 22 inches in diameter, and they can be run safely at the high speed of 1,000 revolutions per minute.

There are no sectors, and external excitation is usually required to start it into action, but when once started the output is large, and it gives good effects with X-ray tubes.

It is probable that the labour of keeping such a machine clean will more than counterbalance the supposed advantages of saving the cost of a case. In the smoky air of towns the electrostatic attraction of a machine in action will attract soot and defile the plates in less than half an hour.

A very good static machine is made by Mr. A. E. Dean,* with ebonite plates which can readily be removed for cleaning. It can be fitted with sectors if required, and if this addition be

* 82, Hatton Garden.

made to one pair of the plates it is probable that the machine will be more easy to start into action. Some electric lamps are fitted to the stand of the instrument, in order to keep the atmosphere warm and dry around the plates.

It has been proposed to enclose the Wimshurst machine in a strong metal case, and to work it under an air-pressure of several atmospheres, in order to reduce the internal leakage by brush

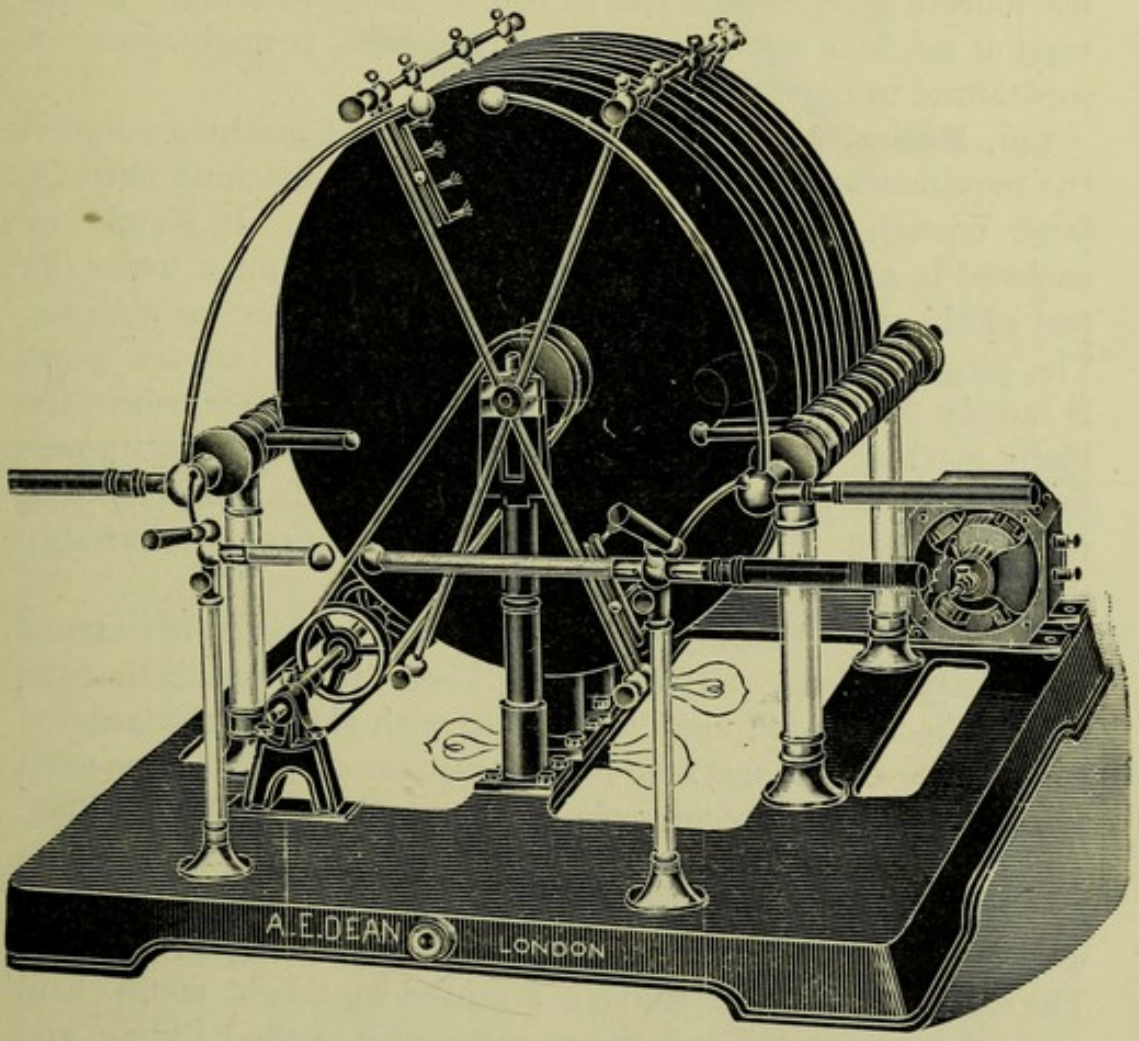


FIG. 131.—THE DEAN STATIC MACHINE.

discharges, which is one of the chief causes of the inefficiency of static machines.

In a machine of this kind, designed and made by Mr. F. Tudsbury, the case is made of stout metal, and it can be filled with compressed air by means of a bicycle-pump. Carbonic acid gas may also be used instead of atmospheric air, and a supply can be kept in readiness in a steel gas-bottle. The advantages of this gas over ordinary compressed air consists in

the fact that it does not yield ozone under the influence of brush discharges, and the destructive effect of ozone upon ebonite can thus be avoided.

At present this machine is only made in small sizes, the stock pattern having plates of 6 inches in diameter, but even this small instrument is said to give sparks 5 inches long, when the internal air-pressure stands at 40 pounds per square inch. A larger machine to give 10-inch sparks can be made to order. If this type of machine were built on a larger scale, it might prove of substantial utility for X-ray work.

126. **Medical Applications.**—In any form of machine adopted the requirements are the same—namely, the machine must be large enough, and built to stand hard work. It should be enclosed in an air-tight case, and pads of indiarubber under the feet of the machine may be used to lessen vibration in working. The progress made in statical treatment in the last few years is largely due to the work done in the United States, where the Holtz machine is now employed widely by medical practitioners for therapeutic purposes and for X-ray work. In country places the occasional X-ray work of general practice is admirably served by a static machine.

Dr. Monell, of Brooklyn, the author of "A Manual of Statical Electricity in X-ray and Therapeutic Uses," recommends that the patient be insulated upon a platform with glass legs connected to one pole of the machine; the electrodes are to be connected to earth, and the second pole of the machine is also earthed. The advantage of this mode of procedure is that the instruments handled by the operator are at zero potential, which makes it unnecessary to use any insulating device to guard against shocks. The earthing of the electrodes is arranged by a light metal chain connected at one end to a gas or water pipe in the building, and fitted at the other end with a handle shaped like a flail, to which the electrodes are hung. This handle, or "electrode holder" (Fig. 132), of Dr. Monell is held in the left hand close to the body, and supports the weight of the electrodes very much as a crane supports a weight. Thus, one hand is used to direct the electrode, while the other supports the weight of it.

For a means of changing the polarity of the insulated platform a solid ebonite rod with brass terminal knobs is fixed in a wooden clamp between the dischargers of the machine (Fig. 133). The upper knob is for the earth connection, the lower is for the con-

nection to the platform. In this way either pole of the machine can be put to earth while the other is connected to the platform.

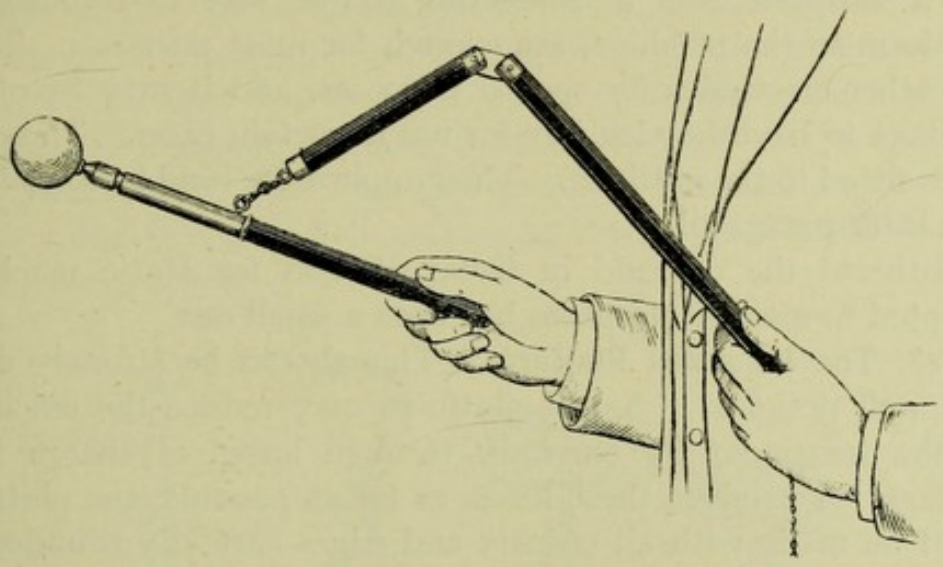


FIG. 132.—DR. MONELL'S ELECTRODE HOLDER.

127. **Accessory Apparatus.**—The accessories which are used with the static machine are as follows: A platform with glass

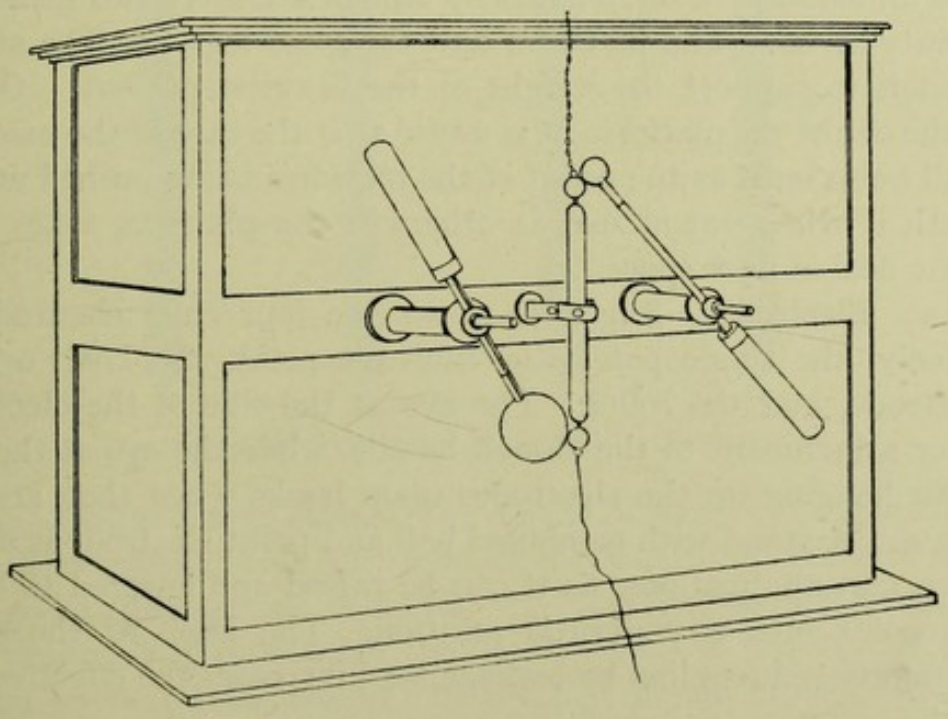


FIG. 133.—FRONT OF CASE, SHOWING EBONITE ROD WITH CONNECTIONS TO EARTH ABOVE AND TO PLATFORM BELOW AND ARRANGEMENT OF POLES.

legs, chains for earthing conductors, a single-point electrode, a multiple-point electrode, a brass-ball electrode, a brass roller, and a Monell's handle for holding these; also a swinging brass

rod carrying a wire tassel, which is best attached to the case of the machine as shown in Fig. 130. These, with a sheet of brass for a footplate, and a connecting rod or wire to connect the platform to the machine, are enough for most purposes. There are other electrodes for special purposes, and it may be of advantage to have Leyden jars for use in certain cases. These are often fitted to the machine. Their applications will be considered in a later paragraph.

Hitherto the demand in Great Britain for static machines adapted to medical purposes has been a small one.

128. **The Insulated Platform.**—This should be strongly made and well designed. A bad platform may reduce the efficiency of the treatment by one-half, through losses of charge from leakage. To reduce these losses as far as possible, the platform must be made with all corners and edges carefully rounded off and made smooth; the glass legs should be at least ten inches long, and twelve inches is even better. There should be a rounded beading or edging to the platform, to prevent the chair or stool from slipping off through any movements of the patient. The dimensions recommended by Monell are forty-two inches by twenty-seven. The platform and the glass legs must be strong enough to support the weight of the heaviest patient. Owing to the size of the platform, it is useful that the case of the machine shall be so built as to permit of the platform being pushed underneath it when not in use, as otherwise the platform takes up a great deal of floor space.

129. **Electrodes.**—Fig. 134 shows the four chief electrodes—namely, the single point, the multiple point, the knob or ball electrode, and the roller. The eye at the side of the electrode is for attachment to the Monell handle, while the eye at the end is for hanging up the electrodes upon hooks when they are not in use. A stand with combined ball and point electrode is useful in certain applications, as it can be raised and lowered to bring the point into any desired position. The knob at the other extremity reduces loss by leakage, and increases the effectiveness of the point.

The single-point electrode is used for giving the static breeze, and Bordier recommends a blunt point with an angle of 90 degrees as most effective. The multiple point is for the same purpose, its effect being rather stronger. The ball electrode is three inches in diameter, and is used for administering sparks. The roller also

gives spark discharges, but in a special way. It is used by rolling it over the surface (clothed) of the patient. When this is done, showers of very short sparks are given off, of a length equal to the thickness of the layer of clothing between the roller and the skin. These short sparks produce a very strong sensory effect, and the roller electrode must therefore be used only with very rapid movements, otherwise the sensation becomes unbearable. It is a valuable electrode in certain conditions, and its effects are highly stimulating.

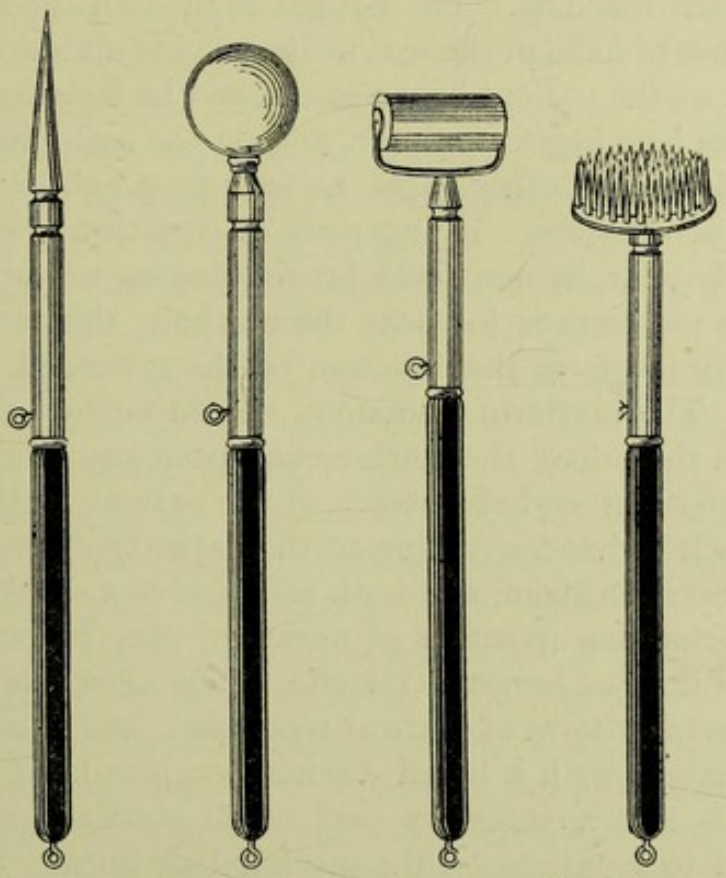


FIG. 134.—ELECTRODES FOR STATICAL TREATMENT.

130. **Distinction of Poles.**—To test the polarity of the machine, take the earthed point electrode in the hand, and present it to a knob of the machine in action. Gradually bringing it nearer and nearer, as it approaches the positive knob a star of light will appear on the point, even at a distance of several inches, and this star of light will remain without much alteration until the point is brought up almost into contact with the knob, when small sparks pass. If approached to the negative pole in the same way, the discharge takes the form of a visible brush or spark when the point is still at a distance of two or three inches from the knob. It is easy to recognise these differences in the dis-

charge to the point, and from them to know which pole is the positive and which the negative.

131. **Simple Charging.**—The patient is to be seated on a stool or chair on the insulated platform, and the brass plate connected with the machine by a wire or chain, or brass crook. On the brass plate is placed a footstool, and on that the patient rests his feet. The machine is then set in action and its polarity tested. Then bring the positive pole into contact with the conductor to the platform, and take the other one to the earth connection and start the machine. The patient is then charged positively. The presence of nails in the seat of the stool is undesirable.

As soon as the patient becomes charged he feels certain sensations. The hair begins to move, and on the scalp and face, and to a less degree on other parts, he feels as if lightly touched by gossamer or cobwebs. If any piece of furniture or other object or person be near, he may feel a breeze blowing towards him from it. If the platform is too near the machine, this breeze will be particularly felt from the direction of the grounded pole of the machine. The platform, therefore, should be two feet or more away from the side of the machine and from any furniture or the walls of the room, and the friends of the patient must be warned not to touch or hand anything to the patient, otherwise a spark will pass between them, and both will receive a shock.

Simple charging (positive or negative) may be continued for fifteen minutes or longer. Its effects are agreeable and tonic. It is the mildest form of statical treatment, and is usually given in combination with a brush discharge to the head or spine or both ; it is also a necessary part of all statical treatment administered to a patient on the insulated platform. Usually the patient is charged positively. It has been said that the negative charge produces feelings of prostration, while the positive produces invigoration. This is probably incorrect—at least, it is not supported by everyday experience—though the idea serves to decide that when simple charging is desired the positive charge shall be preferred.

132. **Charge and Discharge.**—In addition to the continuous electrification described in the last paragraph, there is a method of alternately charging and discharging the patient which is described by Dr. Monell, and recommended by him as a more energetic tonic treatment than the simple charging. He has given it the name of " Potential Alternation," and it is performed

as follows : While the patient is being charged, the knob or ball electrode, grounded as usual, is brought near to the knob of the machine from which the patient is being charged. As it approaches, a sharp cracking spark passes, and the patient is discharged, to be immediately charged again from the machine and again discharged in the same way as before. The chargings and dischargings follow each other with a rapidity which depends upon the activity of the machine and the width of the gap across which the spark must leap. The patient's hair can be seen to oscillate in time with the sparks, especially if the head breeze electrode be in position during the application. This method has the disadvantage that the stream of sparks makes a distracting noise which some patients cannot endure. Other patients do not mind the noise so much and find the application not unpleasant.

133. **The Brush Discharge or Breeze.**—If when the patient is charged on the platform a grounded point electrode is presented to him, he feels the sensation of a wind blowing towards him from the point ; this is the electric breeze, or wind, or *souffle électrique*. It can be felt when the point is a yard away, but becomes much more strongly felt when the point is brought nearer, right up to the distance at which the discharge changes from the silent discharge to that of sparks. The safe distance varies according to the polarity of the patient. When he is positive the grounded point can be brought much closer without sparking than when he is negative. The breeze which is felt as a cool wind upon the bare skin acquires a pricking hot character when directed upon covered parts, and the prickly sensation is greater when the patient is positively charged. Usually, therefore, the patient is charged positively, except when the mildest form of breeze is desired, as may be the case with timid or unaccustomed patients. The breeze produces a very grateful sensation when applied to the scalp and to the nape of the neck, and it is usual to arrange a special electrode for this head breeze by means of a hinged arm supporting a wire tuft or tassel, or a crown-shaped metallic arrangement. In Fig. 130 this is shown as a rod projecting from out one top corner of the case, and has a universal joint enabling it to be swung out or in and raised or lowered to bring it into place over the patient's head as he sits upon the platform. The scalp can also be " breezed " mildly by the point electrode held in the operator's hand.

The breeze is called the " negative breeze " when the patent

is positive, and *vice versâ*. The breeze can be varied in strength by varying the distance between the point and the patient's surface. When the strongest effects are desired, the point (single or multiple) is brought as close as is possible without sparking ; the effect then is something like a douche of hot water, and may be so strong as to be unpleasant, especially if kept acting for long upon one spot. It is more easily borne if the electrode is kept moving over the surface. The effect of a strong negative breeze upon the spinal region and the back is very invigorating, and it leaves a warm glow or after-effect. As the effect of clothing in modifying the sensations of the breeze discharge is so marked, it is occasionally useful to vary the thickness of clothing to suit the requirements of the case, and this can best be done by using a woollen shawl, which may be thrown over the patient at any part where the strongest stimulation is desired. All the fabrics used for clothing do not behave alike in modifying the sensations produced by the breeze, for occasionally the corsets (or the back of the waistcoat in the case of male patients) may prevent the breeze from penetrating satisfactorily. It is not often, however, that difficulties arise, and when they do it is generally possible to overcome them. Occasionally the metal parts of the stays, or buckles, or hairpins, or fine gold chains worn round the neck, or a steel key-chain in the side pocket will cause some pricking or discomfort at the wrong place, and must be attended to.

When the patient's skin and underclothing is very moist from perspiration the effect of the breeze is greatly diminished, and patients must be told not to walk hurriedly to keep their appointments in warm weather ; occasionally in very close summer weather the roller must be used instead of the point.

The breeze may be modified and strengthened by interrupting the charge as it passes from the machine to the patient ; this is easily done by moving the conductor of the machine a little distance from the knob which leads the current to the platform.

The effect of the breeze is to produce definite cutaneous sensory impressions which can be adjusted so as to be either soothing or highly stimulating. In many cases of neuralgic pain, including headache, the effect is quite magical—that is to say, the breeze skilfully directed upon the affected region for five or ten minutes will remove the pain entirely. In addition to this local effect, which is often very valuable, there is a

general invigorating effect from the breeze applied to the head, the nape, and the spine, for which patients are very grateful. The sensations may be compared to the effect of those douches used in hydropathic establishments, with the great advantage that they can be given to the patient without any removal of clothing.

134. **Treatment by Sparks.**—For giving sparks the knob electrode is used, and as the sensation of a spark is disagreeable they must be given in as skilful a way as possible to avoid all unnecessary discomfort to the patient. The important point is to give only one spark at a time and not a volley. To do this the knob, earthed as usual, is swept quickly in a curve past the place at which the spark is aimed, so that it is away again and out of range before a second spark can follow the first. With a little practice this becomes easy. The sparks may be repeated as often as it is judged to be necessary. Long sparks must not be directed upon bony prominences, nor upon any place where the bone is thinly covered with soft tissues, nor upon the face or other sensitive parts. The length of the spark can be decreased by partially discharging the patient before giving the spark, and this is easily done by the operator placing his foot upon the edge of the platform, and so causing it to leak away part of its charge. Sparks from a knob are more severe than those from the point or roller ; the impression produced by a single well-directed spark is just that of a blow, the sensation depending mainly upon the sudden muscular contraction caused by the spark. It is as well to give the patient notice before each spark. With ladies the sparks, if used at all, must be weakened in the manner indicated.

135. **The Roller : Electric Frictions.**—When the roller is rolled over a clothed surface, showers of short stinging sparks pass off from it to the patient, and the thicker the layer of clothing under the roller the sharper are the sensations. Thus they can be made stronger by a woollen shawl thrown over the clothing, and milder by the removal of an outer garment. The sensation is severe, and leaves a tingling glow behind it which persists for some time. To use the roller it is best first to discharge the patient by means of the foot on the platform, and then quickly to put the roller in place, withdrawing the foot and sweeping the electrode over the surface immediately. All should be done in a few seconds, or the patient may protest. As in the case of long sparks, patients like to receive notice of the roller, if it is to be

applied to any part of the back where they cannot see it coming.

136. **The Leyden Jar.**—This apparatus (see § 13) was discovered in 1749. Owing to the arrangement of its coatings it has a large capacity, and in its discharge there is a larger "current" than in the spark from the prime conductor of a machine as ordinarily constructed.

This makes itself felt as a more severe shock when the discharge takes place through any portion of the body. The Leyden jar is therefore used when it is desired that the patient shall receive a sudden shock.

In former days the comparative feebleness of the machines in use made it necessary at times to use Leyden jars to secure the strong effects which can now be produced more agreeably by the ordinary spark discharge from a knob electrode. They were used by first charging them from a machine, and then bringing them to the patient and discharging them through him by means of conductors. They were also used in connection with an apparatus for regulating the sparking distance, which is known as Lane's unit jar and discharger, and in a book on "Electricity and Medical Electricity," written by Adams in 1791, the frontispiece illustrates a physician of the period electrifying the muscles of a child's forearm in this manner with ordinary conducting-cords and electrodes.

This mode of treatment, however, seems to have been completely forgotten, for it is not mentioned in later writings so far as I am aware. In recent years a much better method of using Leyden jars has been devised and brought to perfection by Dr. W. J. Morton of New York, and, as worked out by him, it has now become a regular and generally accepted method of treatment. In a report presented to the American Electro-Therapeutic Association in 1900, the early methods of using Leyden-jar discharges are fully described, with diagrams; the method of Dr. Morton (see next section) is compared with the ancient methods, and its utility and originality is upheld.

137. **Dr. Morton's Method.**—In the illustration of the Wimshurst machine (Fig. 129) two Leyden jars are shown with their inner coatings connected to the prime conductors, one to each; the outer coatings are also connected by a wire, which can be removed at will. When the outer coatings are disconnected, or the jars are removed entirely, the machine in action produces

a stream of thin purplish sparks; and if the finger be placed between the discharging electrodes, the sensations, though unpleasant, are of the nature of a slight pricking rather than of a shock. If the jars are now connected to their respective electrodes, and their outer coatings are joined by the wire, the sparks between the electrodes alter their character, becoming less numerous, much brighter, much longer, and much more noisy. They also produce severe shocks if the fingers are placed in their path. As the distance between the knobs of the discharging electrodes is increased, the sparks become louder, more vivid, and less frequent, until the air-gap is made too great for the discharge to cross. If the wire joining the outer coatings of the jars be interrupted by a short air-gap sparks will leap across it simultaneously with those passing between the electrodes.

Many machines are fitted with a pair of binding-screws in the path joining the outer coatings of the Leyden jars. This makes it easy to connect or disconnect this part of the circuit. When a wire is used to bridge over the interval between the binding-screws the outer coatings are connected, when it is removed they are disconnected. Dr. Morton of New York has advocated the use of this portion of the circuit between the outer coatings for purposes of treatment. With a pair of ordinary conducting-cords and electrodes (Fig. 135) attached to the binding-screws mentioned above, Leyden-jar shocks can be administered to a patient, and their severity can be controlled by adjusting the distance between the discharging-knobs of the prime conductors *d*, *d*. When the machine is in action a shock is felt by the patient every time a spark passes between the discharging-knobs. Dr. Morton has given this method the name of treatment by "static induction," and the utility of the method for purposes of treatment is undoubted. Further, Dr. Morton has claimed that by the use of very small Leyden jars, and with the discharging-knobs very close together, the shocks become almost painless, while still setting up vigorous contractions in the muscles, and may then be made extremely useful for purposes of testing.

It is of the utmost importance to adjust the sparking distance between the discharging electrodes on the machine before commencing the treatment; an eighth of an inch is generally sufficient. With quarter-inch sparks the treatment is severe, but the severity of the shock depends also upon the size of the jars, and is more severe with large jars.

Modern statical machines for medical treatment are now generally fitted with pairs of Leyden jars of several sizes for Morton's method, and have a simple switch arrangement for connecting or disconnecting the jars as required. The rate at which the shocks follow each other is determined by the speed of the machine. The effect produced is comparable to that of a slowly-acting induction coil, and moistened electrodes applied to the bare skin are to be used.

By a further application of a helix of wire between the outer coatings high-frequency effects can be obtained.

The regulation of the discharges in Morton's method is

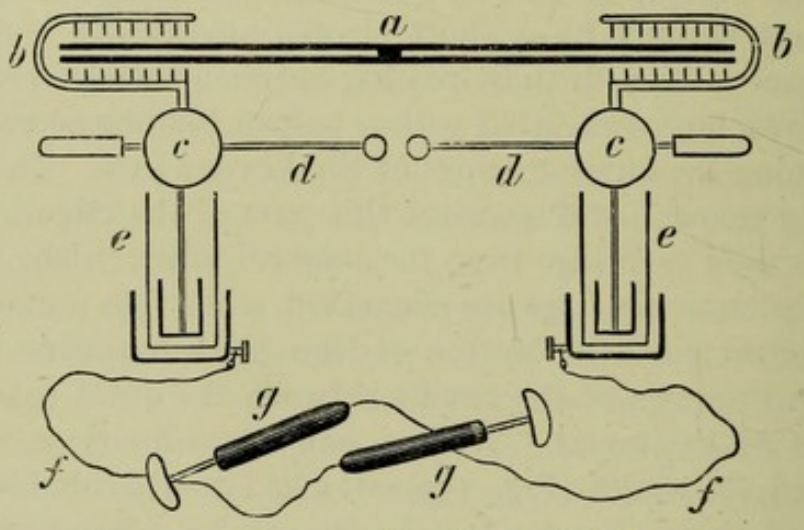


FIG. 135.—PLAN OF DR. MORTON'S METHOD.

a, Plates of machine; *b*, collecting combs; *c*, prime conductors, with discharging-rods, *d*; *e*, Leyden jars; *f*, *g*, wires and electrodes attached to their outer coatings.

effected by adjustments of the sparking distance between the knobs of the discharger *d*, *d*. This varies the potential at which the jars can discharge. It has also been proposed to vary the capacity of the condensers, and this has been done by Marie and Cluzet by using Leyden jars of special shape in which the coatings can be brought near together, or separated more widely apart.

Truchot* has designed an ingenious contrivance for applying Morton's method when the machines are unprovided with Leyden jars. A tube of glass is taken long enough to reach horizontally across from one prime conductor of the machine to the other, and a little over, and two tinfoil armatures are glued

* *Archiv. d'Élect. Médicale*, 1889, p. 333.

to its outer surface at points where they touch the two prime conductors.

Inside the tube two movable metallic cylinders slide; they act as the inner coatings, and correspond to the outer armatures of tinfoil. When pushed in a certain distance their coatings come face to face with those on the outside of the glass tube. A pair of conducting-rods with binding-screws are attached to them, and the cords for the patient are fastened to these. The capacity can be varied by displacing the internal armatures from their position in the neighbourhood of the outer coatings.

In France the name *franklinization hertzienne* is often applied to Morton's method, and the opinion has been expressed by some writers that the discharges through the patient in Morton's method are oscillatory discharges of high frequency. Reference to the formula given in § 138 will show that this is improbable, because the resistance of the body is too high and the self-induction is too low to give the conditions necessary for oscillations in the circuit. Taking even the most favourable estimate of the resistance, the other quantities must differ considerably from those of the usual conditions of the experiment.

Mr. Rimington, writing on this subject in the *Electrical Review* some years ago, calculated a case for a Leyden jar of about one pint in size, the capacity of such a jar being taken at 0·0012 of a microfarad. He says: 'Suppose we take the resistance of the human body as 300 ohms, then the self-induction in the current must be greater than 27 microhenries to obtain oscillations, while the self-induction of the human body and the spark-gap would be less than this. With a jar of greater capacity the case will be still worse,' and we may add that with a higher figure for the resistance of the body, the case will be much more unfavourable to the existence of oscillations.

CHAPTER VII

HIGH POTENTIAL APPARATUS—DISCHARGES OF HIGH FREQUENCY

Oscillatory discharges—High-frequency apparatus—Oudin's resonator—Modes of application—Electrodes.

138. **Oscillatory Discharges.**—It has already been stated (§ 13) that, under certain conditions of the discharging circuit, the discharge of a condenser is an oscillatory one. The oscillations die away very quickly, but while present they may have a periodicity of hundreds, of thousands, or of millions, a second.

The conditions which determine whether a condenser discharge shall be oscillatory or not were expressed mathematically by Lord Kelvin (then Professor William Thomson) in 1853.

He showed that the factors concerned were the resistance R of the circuit, its self-induction L, and the capacity C of the condenser. Then, if the resistance of the circuit is greater than the expression $\sqrt{4L/C}$, the discharge is a continuous one ; but if the resistance is less than that quantity the discharge is oscillatory.

To illustrate the phenomena by analogy the behaviour of water in a hydraulic apparatus is commonly employed. Imagine two jars of water connected by a pipe in which is a tap. When the tap is open the jars are placed in communication, so that water can flow from one to the other. With the two jars standing at the same level and the tap closed, one jar is filled with water and the other is left empty. This compares with the charging of the condenser. The tap is then opened suddenly, and the water flows through the pipe, until finally a state of equilibrium is reached, with the water standing at the same level in both jars. This represents the discharge of the condenser. If the pipe of communication is narrow, there is resistance to the free passage of the water, and the flow is a con-

tinuous gradual one. If the pipe is a wide one the water flows rapidly, and equilibrium in the two vessels is only reached after a series of oscillations in which the height of the water level is alternately greater in the first and in the second of the jars.

So, again, the discharge of a condenser has been compared to the vibration of a spring which has been bent and is let go. If free to move, the spring reaches its position of rest only after a series of oscillations or vibrations. It comes to rest without oscillations if its movement is opposed by sufficient friction. In the case of the electrical oscillation friction is represented by the ohmic resistance of the circuit.

With small capacities and with small self-inductions, the rate of oscillation is more rapid than with large values of either of these components.*

For rapid oscillations circuits should have small capacities, low self-inductions, and very low resistances. Increasing the capacity or the self-induction slows the rate of oscillation, and increasing the resistance damps the tendency to oscillation, so that any increase of resistance above a certain critical value will altogether damp out the tendency to oscillation.

A most lucid exposition of this subject will be found in Lodge's "Modern Views," Lecture 3, on "The Discharge of a Leyden Jar." This should be studied by everyone who intends to use high-frequency apparatus. Sir Oliver Lodge has pointed out that it was Joseph Henry of Washington who first arrived at the conviction that the discharge of a Leyden jar was oscillatory, and he quotes the following remarkable words of Henry: "The phenomenon requires us to admit the existence of a principal discharge in one direction, and then several reflex actions backward and forward, each more feeble than the preceding, until the equilibrium is attained."

Of late years Elihu Thomson, Nikola Tesla, and D'Arsonval have developed the study of these "high-frequency" phenomena, and have obtained some remarkable results. The apparatus required is comparatively simple; the principle is to charge Leyden jars whose outer coatings are connected by a

* The formula for determining the time T of oscillation is as follows: $T = 2\pi\sqrt{CL}$, when the resistance of the circuit is very low, as is the case in the solenoid of a high-frequency apparatus (Fig. 136). When the resistance is high the equation becomes the following: $T = \frac{2\pi\sqrt{CL}}{\sqrt{1 - \frac{CR_2}{4L}}}$

helix of wire, or solenoid, as in Fig. 136. The inner coatings of the jars terminate in knobs, whose distance apart can be adjusted to suit the sparking distance of the charging electromotive force. The jars can be charged from a Wimshurst machine or from an induction coil of large size, or, through a high potential transformer, from the alternate-current supply mains. The output is least in the first method.

The jars, when charged to a sufficient potential, discharge in an oscillatory manner across the air-gap and through the solenoid connecting the outer coatings, and the latter becomes the seat of electromagnetic induction effects, comparable to those of

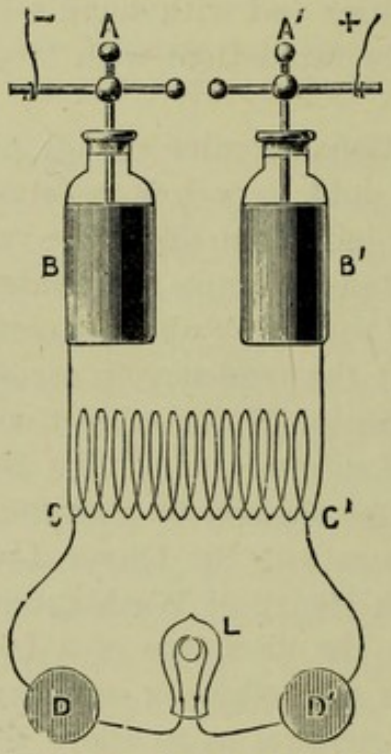


FIG. 136.—ARRANGEMENT OF APPARATUS FOR HIGH-FREQUENCY EXPERIMENTS.

the primary circuit of an induction coil, so that a derived circuit formed by wires leading from the two ends of the helix yield a current, as do the wires of the "primary current" (§ 48) of a coil. In fact, the apparatus may be regarded as a modified induction coil, the exciting current being supplied from the discharge of the jars instead of from a voltaic cell, while the spark-gap takes the place of the contact-breaker. The suddenness of the discharge causes the changes in the magnetic field of the circuit to be very rapid, and consequently (§ 46) sets up very powerful induction effects, both in the solenoid itself (self-induction) and around it (mutual induction), and a secondary

coil wound over the solenoid gives very conspicuous effects. Fig. 136 shows an arrangement, due to D'Arsonval, for demonstrating high-frequency effects. D, D′, represents two persons holding between them an incandescent lamp L, and having their other hands connected to the terminal points of the solenoid; under these conditions the current between C and C′ traverses the lamp and the arms of the two experimenters, and the lamp glows brightly, though they feel no shock.

The solenoid is usually made of about twenty turns of thick copper wire. Although the true ohmic resistance of the whole helix is excessively low, only a very small fraction of an ohm, its impedance or virtual resistance to these very rapidly oscillating currents is so high that if two neighbouring turns are approached by a finger there will be strong sparking from one turn to the next through the alternative path offered by the finger-tip, in spite of the relatively enormous ohmic resistance of the latter; and if a straight or slightly bent piece of copper wire be brought near to the two ends of the coil, loud crackling sparks will leap to it. Professor Fleming,* in dealing with this matter, says: "If the difference of potential between the ends of a conductor is established with great suddenness, the resulting electric flow is less and less determined by what may be the true resistance, and more by the inductance of the conductor. We have a mechanical analogy in the case of impulses or sudden blows given to heavy bodies, which well illustrates how strikingly force phenomena may be altered when for steady or slowly varying forces we substitute exceedingly brief impulses or blows."

"If an explosive, such as gun-cotton, is laid on a stone slab in open air and simply ignited, it burns away with comparative slowness, the slab is uninjured, and the evolved gases simply push the air away to make room for themselves. But it is well known that by means of detonators the same explosive can be fired with enormously greater rapidity, and in this case the blow or impulse given to the air is so sudden that it has not time to be pushed away, and its incapability of receiving a finite velocity in an infinitely small time bestows on it an inertia resistance, which causes nearly the whole of the effect of the explosion to take effect downwards on the slab, and this last is shattered. The inductance of conductors introduces a series

* "The Alternate-Current Transformer," vol. i.

of phenomena which are the electrical analogues of the above mechanical experiment. A conductor of sensible inductance can no more have a current of finite magnitude created in it instantaneously than a body of sensible mass can have a finite velocity instantaneously given to it. In both cases there is an immense resistance to very sudden change of condition. Accordingly, the study of the behaviour of conductors under exceedingly sudden electric blows or electromotive impulses leads us to consider some very interesting effects."

139. **The "Skin Effect."**—Another point of importance in the phenomena of high-frequency currents is one which is commonly spoken of as the skin effect. By this is meant that, with rapidly varying currents, the distribution of current in the thickness of a wire conductor is irregular. Silvanus Thompson, in writing on this point, says that with rapid frequencies the currents do not flow equally through the cross-section of the conducting wire, but are confined mainly to its outer surface. He mentions that even at a frequency of 100 per second, the current at a depth of 12 millimetres from the surface is (in copper) only about one-seventh of its value in the surface layers. In iron wires the depth of the skin for one-seventh value is about one millimetre. For such rapid oscillations as the discharge of a Leyden jar through a short, straight copper wire where the frequency is one of several millions, the conducting skin is probably less than one-hundredth of a millimetre thick. Hollow tubes in such cases conduct just as well as solid rods of equal outer diameter. The conductance is proportional to perimeter, not to section.

In some experiments of Sir Oliver Lodge,* two wires of very different thicknesses were taken; each wire was about 100 inches long, and was bent into a single circle. One had an ohmic resistance of 2·6 ohms, and the other of 0·004 ohms; thus, one had a resistance 650 times greater than the other. The virtual resistances of the two wires, for rapidly varying currents, were very different from their true ohmic resistances, and their relative conductivity for these currents was also very different from their relative conductivities with steady currents. The resistances were found to be 4 and 6 ohms with oscillations at the rate of a quarter million per second, 43 and 78 ohms at three million oscillations, and 180 and 300 ohms respectively at twelve million oscillations.

* "Lightning Conductors and Lightning Guards."

140. **Magnitude of High-Frequency Currents.**—That the currents which flow through the experimenters' bodies and the lamp in D'Arsonval's experiment are really large must be accepted. It is less easy to say how large they may be. Their apparent magnitude certainly varies with the magnitude of the apparatus used. As measured by means of a hot-wire ammeter, they may give readings corresponding to 100, or even up to 500 milliampères or more of steady current There are difficulties in understanding why they should produce such slight physiological effects, and various explanations have been put forward, but none appear quite satisfactory. Although the currents may not have the values indicated by the ammeters, it is at least certain that there is an expenditure of a considerable amount of energy in the circuit, for this can not only be measured in a hot wire instrument (§ 58), but might even be recovered in the form of work, if it were thought worth while to devise an apparatus for the purpose.

The subject was discussed freely in the electrical journals about ten years ago. In the *Electrical Review* the Hon. Charles Parsons is quoted as saying that a 100-volt lamp taking 0·6 ampère to bring it to incandescence with a steady current would incandesce equally well with 0·006 ampère of mean current, if subjected to short impulses at 10,000 volts.

With this explanation it is necessary to admit that the current must reach maxima approaching 20 ampères, and this, of course, increases the difficulty of explaining the absence of physiological effect.

Although it is a fact that with a high-frequency apparatus no shock is felt when the hands are in good contact with the electrodes, yet if there be an air-gap in the discharging circuit the shocks at once become felt, and the wider the gap the more severe are the shocks. Probably this is the case because the spark-gap renders the discharge non-oscillatory.

These paradoxical effects have given rise to much discussion, but further investigation is necessary before the real explanation of them can be arrived at.

The " skin effect " has been invoked to explain the absence of sensory and muscular effects with high-frequency discharges. It has been said that the current passes only by the superficial layers of the epidermis, and does not penetrate into the body at all, and that it is not felt on this account. The physiological

effects produced by high-frequency discharges would suffice to combat this theory. Moreover, high-frequency currents not perceived by human beings are able to kill small animals in a few minutes. The " skin effect " observed in a good conducting material like a metallic wire is not nearly so definite in conductors like the human body.

Our information respecting the behaviour of conductors such as the human body to high-frequency oscillations is still quite imperfect, and it is probable that the electrical oscillations set up in the human body are quite unlike those produced in a metallic conductor.

When a conductor of high resistance, such as the human body, is connected to two points on a helix at which very rapid changes of potential are occurring, the conductor must be subject to pulses of changing potential tending to set up oscillatory currents of high frequency. For a proper knowledge of the effects actually produced in the body under these conditions it is necessary to consider the effects of the resistance of the body and of its capacity. The high resistance of the body would tend to exercise a very great damping effect, and the capacity would also tend towards a distortion of the waves of current which might profoundly modify the oscillatory character of the current through the body, even though the applied electromotive forces were oscillatory, and of high frequency.

It must be borne in mind that all high-frequency effects studied upon human beings have been made with the subject in shunt to the circuit in which the oscillations take place. The patient is not in the direct circuit joining the outer coatings of the jars, and owing to the body resistance, it would be very difficult to produce high-frequency oscillations in the body when it was so connected. From experiments which have been made in this direction it appears probable that such oscillatory discharges which could be produced by arranging the circuit in accordance with the formula given in § 138 would be quite painful.

141. **Medical Applications.**—The development of high-frequency apparatus for medical work has taken place almost entirely in France, and is based upon the physical and physiological researches of D'Arsonval. The current from the primary helix is that most commonly used in medical applications, and he arrangement shown in Fig. 137 represents the apparatus in

a simple form. The solenoid connecting the outer coatings of the jar is of bare wire, open to the air, as this affords sufficient insulation for most purposes. If a secondary coil is to be used it may be immersed in a vessel of insulating oil, or may be so wound as to leave a large air-space separating it from the primary; the latter may be placed either inside or outside the secondary (Fig. 138). No iron core is used. By means of a transformer a double brush discharge (bipolar effleuve) can be employed, the electrodes being attached to both ends of the secondary winding. Or one end may be earthed, and the other employed for a "unipolar" application.

The methods of applying high-frequency currents to the

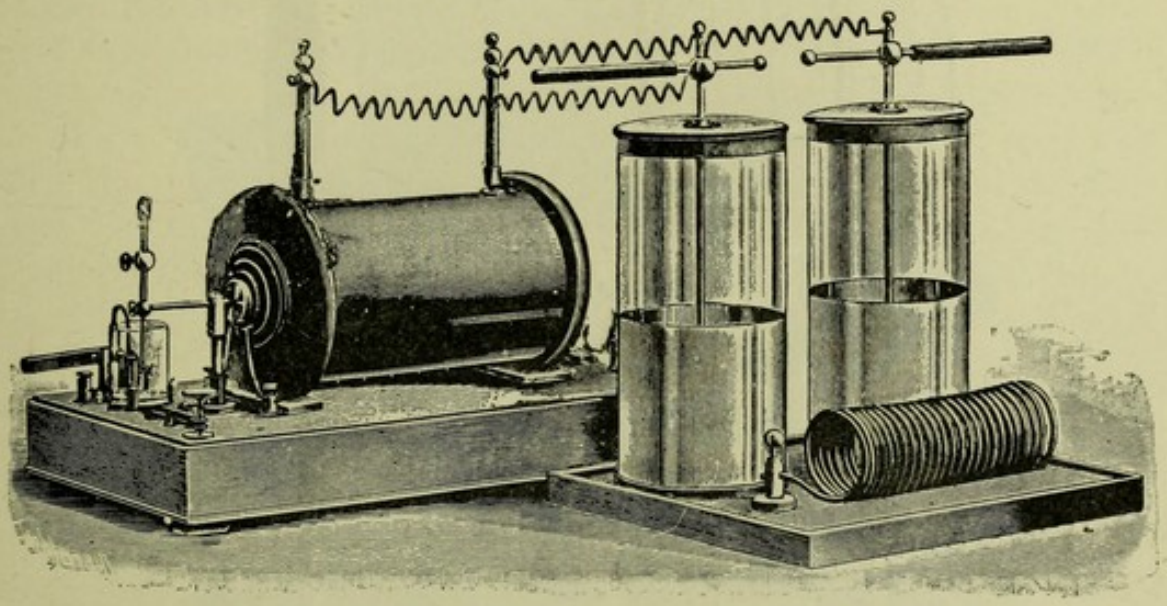


FIG. 137.—D'ARSONVAL'S HIGH-FREQUENCY APPARATUS.

The Leyden jars have the outer coatings joined by a solenoid and the inner coatings fed by an induction coil.

human body which were devised by D'Arsonval will be found in a paper by him in the *Annales d'Électrobiologie* for January, 1898, in which a summary of his previous work is given in a simple form. Three modes of application were originally proposed. In the simplest of these the patient is put in direct connection with the extremities of the helix or solenoid, the electrodes used being the ordinary moistened pads already described (Fig. 51), or some modification of these. They should be of large surface, and must be kept in good firm contact with the skin to prevent sparking and consequent burning at points of imperfect contact. This method is commonly spoken of as the direct application of high-frequency currents.

The second method is by "condensation" or the condenser couch. The patient is connected to one end of the solenoid in the ordinary way, but the other end is attached to a large plate of metal brought near to the patient, but insulated from contact with him. Thus the metal plate and the body of the patient form the armatures or coatings of a condenser arrangement having a large electrical capacity, which is alternately charged

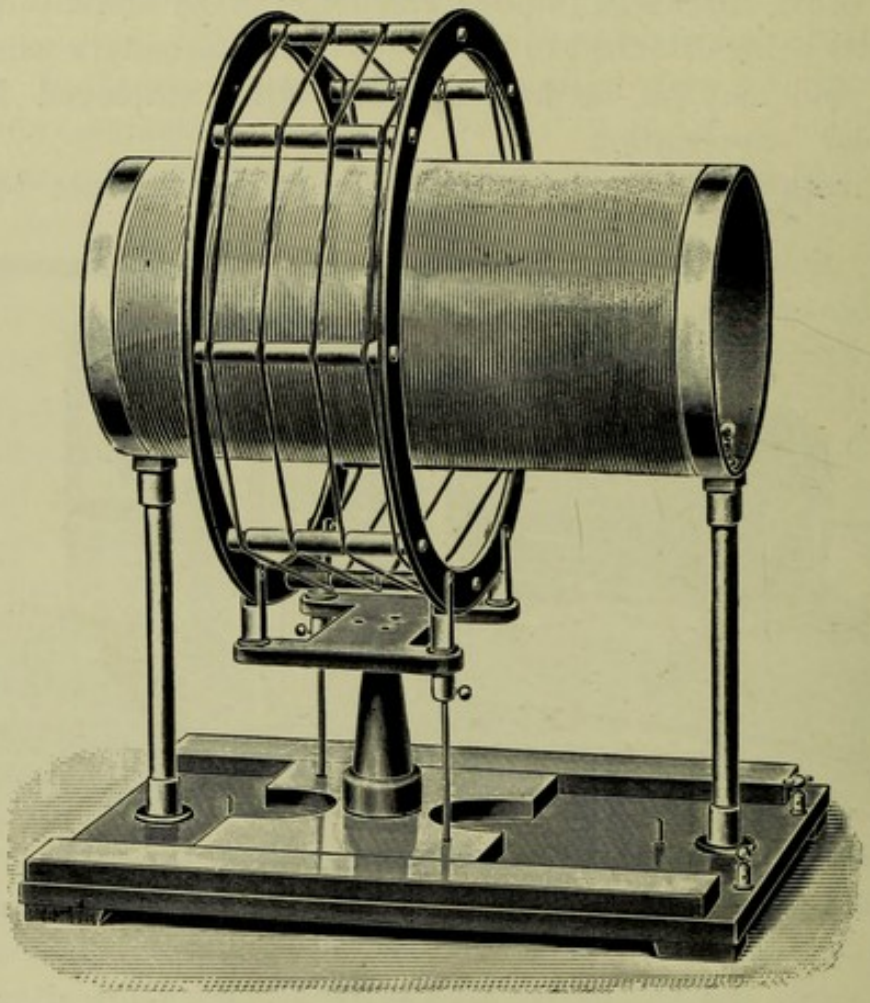


FIG. 138.—HIGH-FREQUENCY TRANSFORMER.

The secondary coil is wound on the ebonite tube, and the primary consists of the four turns of wire seen outside of it.

and discharged as the potentials at the extremities of the solenoid vary. The apparatus is usually arranged in the form of a couch (Fig. 139); the patient lies upon insulating cushions which separate him from the metal sheet which is fixed beneath. The current passes to the patient either by a handle of bare metal held in the hand, or it may be in the form of an electrode applied upon any desired part of the body.

Another mode of application consists in enlarging the size of

the solenoid and enclosing the patient inside it. The patient does not touch any conductor, but is acted upon inductively by the currents in the solenoid which is carrying the Leyden jar discharges. The currents generated in the patient by induction are considerable, so much so that an incandescent lamp held between his two hands is brightly illuminated. This method is called treatment by auto-conduction. Horizontal solenoids enclosing a couch are made, and also vertical solenoids in which a patient can stand or sit (Fig. 140).

In these three methods the applications are general rather than local; the whole body is placed under the influence of the currents, and they may therefore be regarded as methods of general electrification.

142. **Oudin's Resonator.** — High-frequency applications have

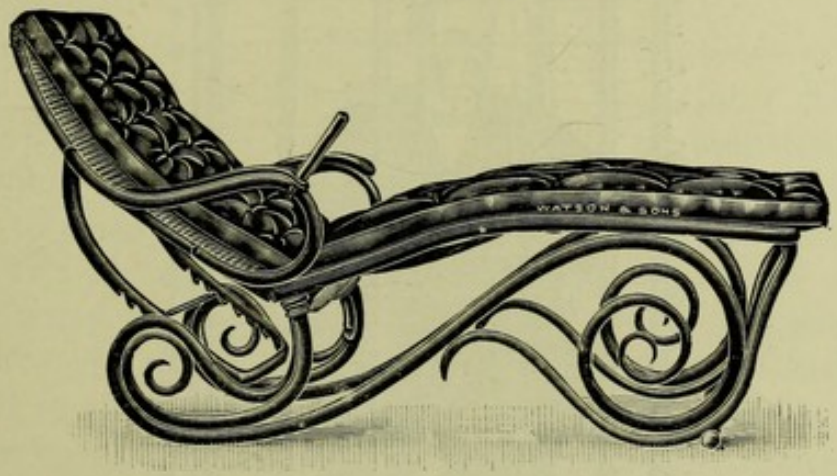


FIG. 139.—COUCH FOR CONDENSATION.

also been used for local effects, particularly in the form of brush discharges. In order to develop these brush-discharge effects it is necessary to obtain potentials as high as possible. This may be done by the use of a secondary coil, oil-immersed or air-insulated, or by an application of the principle of syntony or "resonance." Oudin, in 1892, designed a "resonator" composed of an open solenoid of wire which could be connected up as an extension of one end of the solenoid of a high-frequency apparatus, and served when carefully adjusted to raise the potential to such an extent that a long brush discharge could be obtained from its other or free extremity. Oudin's resonator is now in general use for the production of high-frequency brush discharges, and these have been shown to have a utility in the treatment of various affections of the skin and superficial mucous

membranes. When the effleuve from the resonator is used the other extremity of the solenoid (proximal extremity) is connected to earth.

143. **Description of Apparatus.**—High-frequency currents can be produced with the static machine, or with apparatus connected to the alternating mains ; but in general the instruments

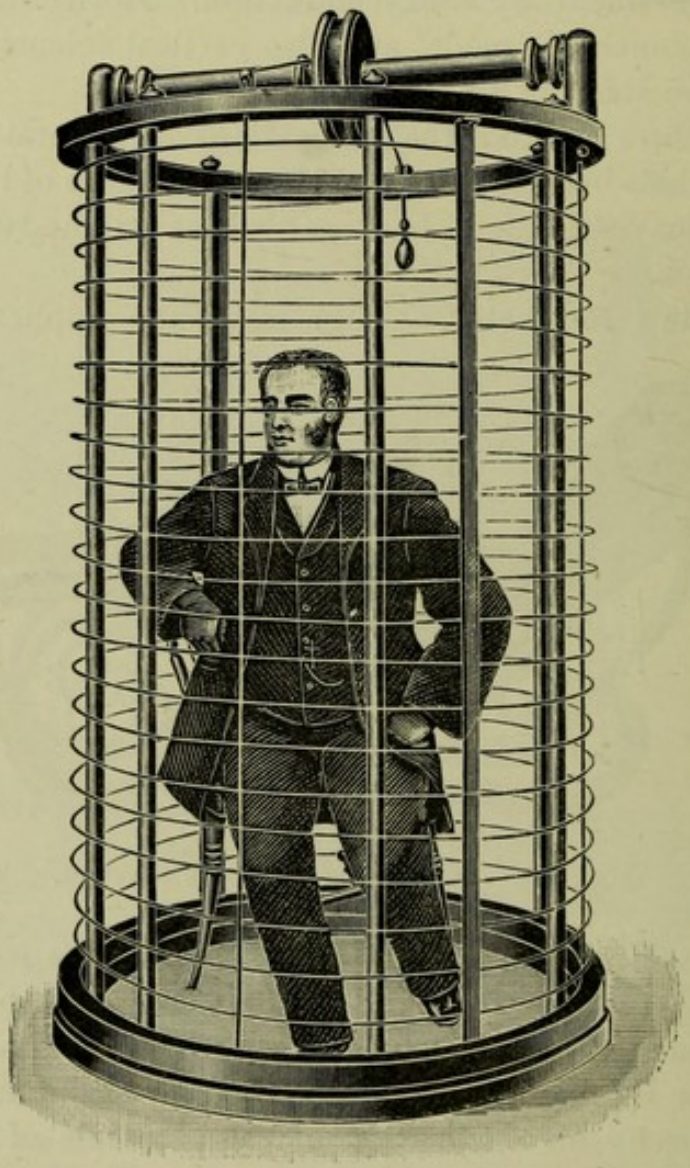


FIG. 140.—LARGE CAGE SOLENOID FOR TREATMENT BY AUTO-CONDUCTION.

in common use for the purpose are worked from Ruhmkorff coils, and practically all the experiences which have been acquired in medical work have been with apparatus worked in this way. High-frequency effects can be produced equally well by means of a step-up transformer, and in places supplied by alternating-current electric light mains this plan would seem to offer substantial advantages in point of simplicity of apparatus. Several

instrument-makers now supply complete sets of high-frequency apparatus for use with high-pressure transformers, and the largest currents can be obtained with ease from apparatus of this kind.

In working from the alternating mains precautions are necessary to protect the patient from the currents of the transformer circuit. Several methods have been proposed for this, but the safest is to use two condensers, just as two Leyden jars are used in working from a Ruhmkorff coil.

So much has been done in connection with high-frequency work in recent years that all manufacturers of electro-medical apparatus now make high-frequency sets in various patterns, and an examination of their catalogues will enable anyone to see how these differ in detail from one another, and to choose the form of instrument which most takes his fancy.

Fig. 141 shows the usual arrangement. On the lower table or platform there are the two Leyden jars. Their inner coatings are connected to the secondary terminals of an induction coil, which should be worked, if possible, with a motor interrupter, and also to a spark box, inside which the discharges take place between two metallic knobs, whose distance apart can be adjusted by a handle. Some quick-lime kept in this box is useful to absorb nitrous vapours. The object of the box is to diminish the sound of the sparks, which is loud and disagreeable. The outer coatings of the jars are connected together through the small solenoid fixed on the side of the upper table. The extremities of the solenoid have sockets for the attachment of the conductors which convey the current to the patient. The resonator consists of the large, partly-covered spiral coil of wire wound on a frame, and shown at the top of the figure. It terminates above in a binding-screw for the attachment of a long flexible cord to carry the electrodes.

The upper two-thirds of the resonator are often covered by a layer of wax or ebonite, while the lower part is left uncovered. This is necessary because the point of attachment of the solenoid to the resonator has to be found by experiment, and varies for different applications. The connection is effected by a jointed metallic arm which makes contact with the resonator wire, as seen in the figure, and it is soon found by experiment that a great effect may be produced upon the brush discharge from the top of the resonator by slight alterations in the point of attach-

ment of the clip. A handle is provided by some makers for slowly revolving the resonator, as this procedure brings the clip into contact with different parts of the resonator in a slowly progressive manner until the best position is found. The adjustment of the contact to the best position on the resonator

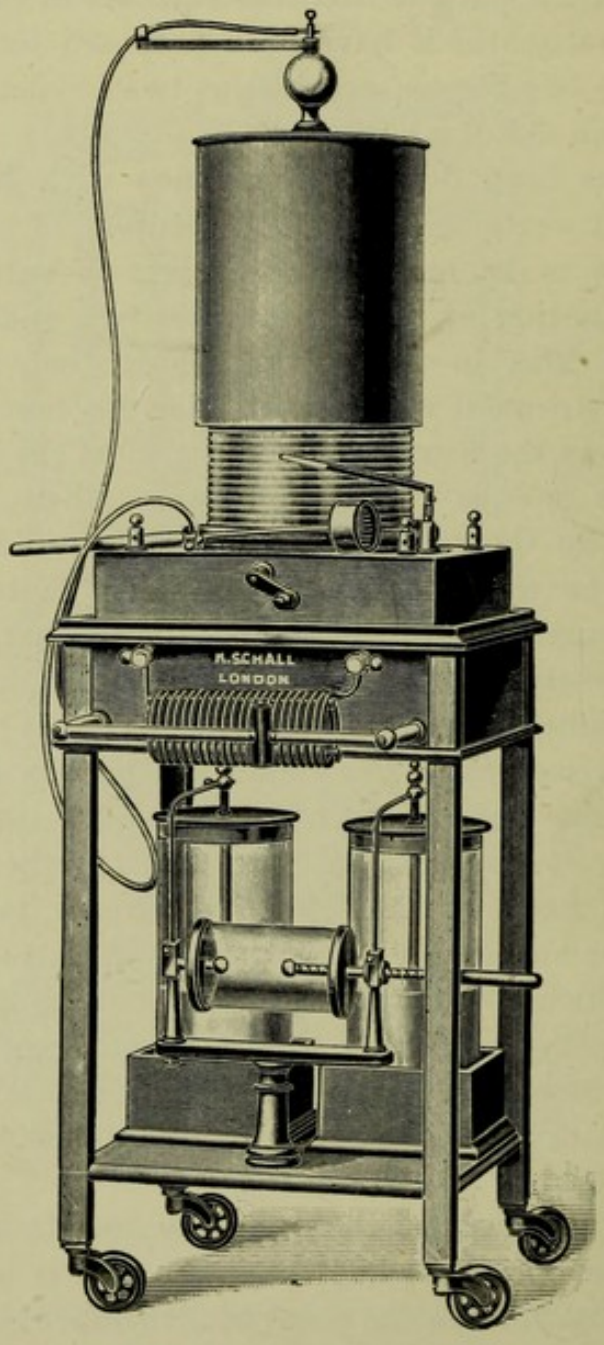


FIG. 141.—HIGH-FREQUENCY APPARATUS.

wire is the tuning of the resonator, and it is an instructive experience to tune the apparatus under different conditions. For instance, if the position for producing the longest brush discharge be first determined when no patient is connected to

the machine, it will be found that the attachment of a patient will throw the apparatus out of tune, and will reduce the length of brush discharge very considerably. If the position of the clip be altered, the best position can again be picked out, and as this point is approached the brush discharge will improve.

It is not necessary to have the solenoid separate from the resonator. One solenoid may be used in both capacities. In this case the lower turns of the wire form the solenoid proper,

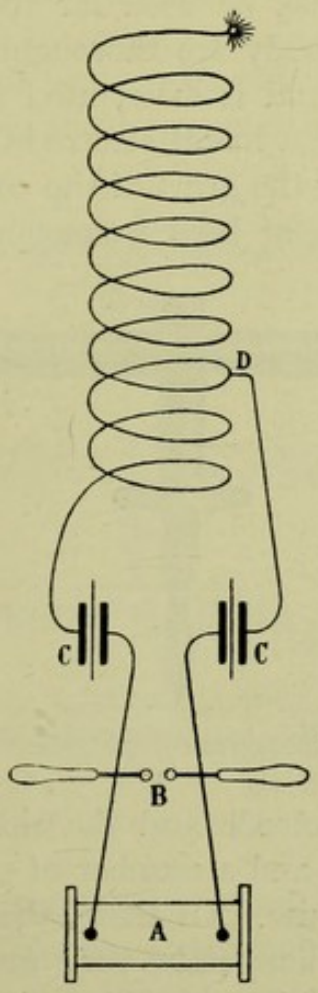


FIG. 142.—PLAN OF RESONATOR.

while the upper turns form the resonator. The outer coatings of the Leyden jars (Fig. 142, C, C) are connected to two points on the solenoid, and the part thus included in the circuit forms the solenoid proper, and is traversed by the discharge current of the jars, while the remaining turns form the resonator. The position of the contact is capable of variation, as already described.

Guilleminot has suggested flat helices for use as solenoid and resonator. These give powerful effects, but are less compact and a little more troublesome in use.

144. **Electrodes.**—For direct applications and general effects the electrodes described in § 68 should be used. They should be moistened, must be in good contact, and must not be too small. In high-frequency applications the magnitude of the currents used is large, and if the contacts with the body are small, there is likely to be a local effect on the skin in the form of burns. The same result will follow if the contacts are imperfect, and the current passes to the patient in the form of sparks. Bare metal may be used for the electrodes, provided the contacts with the body are thoroughly good; thus, a metal cylinder held in the hand is often used for an electrode, as is seen in Fig. 139, where a metal electrode for use in this way is shown affixed to one of the arms of the couch.

In local applications of high frequency the spark or brush

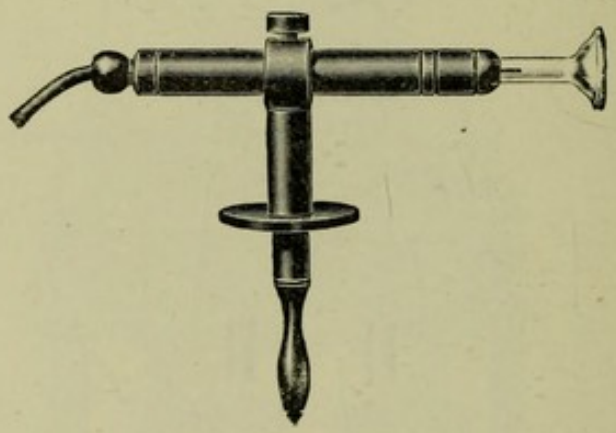


FIG. 143.—ELECTRODE-HOLDER OF EBONITE.

effect between the electrode and the skin is made use of for purposes of treatment, and a number of special electrodes have been devised for local use. Of these, the simplest is composed of a number of metallic points very much like the multiple point electrode described in the chapter on Static Electricity (Fig. 134). Other forms of electrode for local effects have the form of closed glass tubes of different shapes and sizes. They are filled with water or with salt solution, or else they are exhausted and sealed to give them a conducting vacuum internally. A wire through the glass forms the connection between the conductor and the interior of these electrodes. Often they are provided with a glass handle, or in place of this they may be fitted with a metal cap at one end for attachment to a socket in an ebonite handle (Fig. 144).

If the finger be approached to one of these glass electrodes

when connected to the apparatus, a violet brush discharge will be seen between the glass and the finger. This discharge does not come from the inside of the tube, but it is produced at its outer surface by induction (§ 5). It corresponds in polarity and in magnitude with the current flowing to the inner surface of the tube from the wire. If the finger be kept in one position for some little time a sensation of heat will be felt in the skin of the finger, and it can easily be shown that there is an actual production of heat by the discharge. The better the contact between the glass and the skin, the less will be the amount of brush discharge and of heat produced. In applying high-frequency currents locally, the luminous and thermal effects just

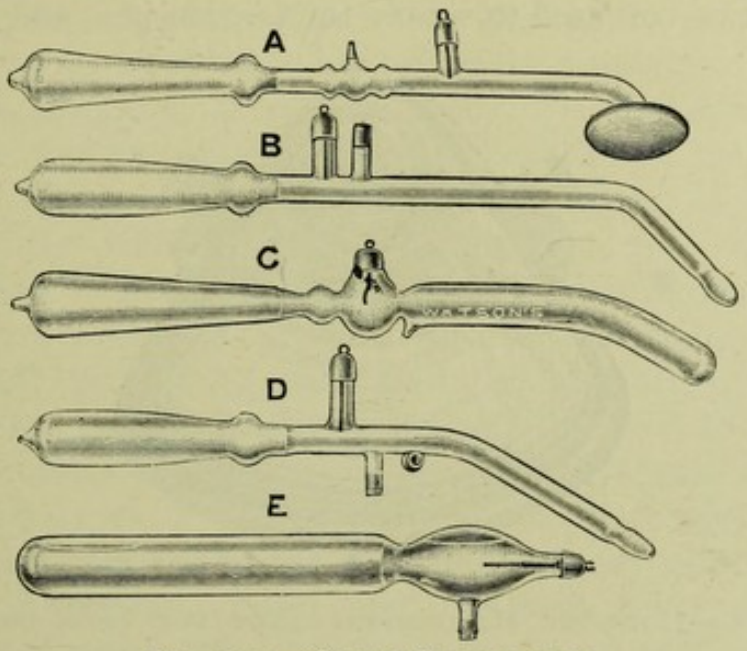


FIG. 144.—GLASS ELECTRODES.

described play an important part. Careless use of the electrodes may blister the skin. In using the multiple point electrode to give a brush discharge care must be taken not to approach the electrode too near the skin, otherwise sharp cracking sparks will pass to the patient, and produce a painful effect, and if repeated several times they may cause small burns, whereas the pure brush discharge is not at all painful. The glass tube electrodes with partial vacuum present an attractive appearance when in action, as they are luminous from the discharge of the current through the vacuum which acts as a conductor. The luminosity of the gas is due to its incandescence, and tends to heat the glass wall of the tube, and these tubes occasionally crack from this cause. They may also be punctured by a

spark, and if this happens the sparks which traverse the crack or puncture produce a disagreeable effect upon the patient, so that the application must be stopped and the tube replaced by another one.

For some purposes tubes exhausted to a very high degree are useful. At exhaustions comparable to those of a Crookes tube the phosphorescence of the glass becomes evident, and such a tube is a source of X rays, and has been used on that account for internal applications where an ordinary X-ray tube is inapplicable.

145. **Graduation and Measurement.** — The strength of the applications can be graduated by regulating the current from the induction coil used to supply the Leyden jars, and by altera-

FIG. 145.—HOT-WIRE MILLIAMPÈREMETER FOR HIGH-FREQUENCY CURRENTS.

tions in the width of the spark-gap. Further, the number of turns of the solenoid which are in parallel with the circuit of derivation may be varied. Sometimes this is done by a spring clip, which may be attached to the solenoid at any desired point, and sometimes by a copper rod, which slides along the inner sides of the turns of the solenoid and short circuits some of them. If the coils of the solenoid and of the resonator form one single spiral, the changing of the point of contact has the effect of varying the number of spires constituting the solenoid proper, and so permits graduation to be effected.

For measurement, hot wire instruments are used. Fig. 145 gives an illustration of the form of instrument in common use.

The magnitudes of current used in high-frequency applications range from 100 milliampères up to 800, or even more. Many operators believe that very large currents should be used if the best results are to be secured.

The galvanometer should be placed in series with the patient when direct applications are used, and between the patient and his point of attachment to the solenoid when treatment is given on the condenser couch. With the method of auto-conduction, measurements of the actual currents circulating in the patient's body cannot be made. Generally it is necessary with this mode of treatment to operate the instrument to its full power. When brush discharges are used, measurement of current is less needed, as the appearance of the effleuve is a guide, but the milliampèremeter may be connected to the top of the resonator.

In all applications of high frequency it is desirable to have a regular action of the interrupter mechanism of the induction coil. On this account a mechanical interrupter is to be preferred to the vibrating hammer type of break. Electrolytic interrupters, by reason of the rapid rate of interruption which they afford, are not very suitable for high-frequency work, especially if currents of large magnitude are required. Professor Fleming* has pointed out that when capacities have to be charged a certain time is necessary, and that the Wehnelt interrupter may have too great a frequency for enabling the charging to take place. This may be observed in high-frequency work by noting that with a very rapid interrupter the length of the spark at the spark-gap of a high-frequency apparatus tends to become less.

* Cantor Lectures on Hertzian-Wave Telegraphy, 1903.

CHAPTER VIII

THE RÖNTGEN RAYS

Kathode rays—X-ray tubes—Measurement of X-rays—Tube-holders and couches—The fluorescent screen—Radioscopy—Radiography—Localization of foreign bodies—Radium.

146. **Kathode Rays and X Rays.**—The discovery of the X rays was made by Röntgen at the end of the year 1895. It followed upon the work of Lenard, who found, when experimenting with the highly-exhausted Crookes tubes, that certain effects could be observed outside the tube. Before that time attention had been fixed upon the phenomena within the tube, and outside effects had not been noticed. Lenard, in 1894, following up a hint given to him by Hertz, and working with tubes provided with an aluminium "window," found that such tubes emitted radiations which could be recognised in the open air outside the window, and that these radiations had the power of exciting phosphorescence and fluorescence* in suitable bodies, and of acting upon sensitive photographic plates. He gave the name of "kathode rays" to the radiations which he had thus discovered. In the following year Röntgen showed that a Crookes tube gave out other rays, to which he gave the name of "X rays," and that these were of a different character from Lenard's kathode rays, inasmuch as they easily penetrated considerable thicknesses of bodies opaque to light, and could be made to produce impressions on a photographic plate, whereby any inequalities of density in a given object could be registered in the form of a photograph. Their penetrating power was much greater than that of Lenard's kathode rays.

After this it was a natural step to take a photograph showing

* The word "fluorescence" is used to signify a phosphorescence which does not last for any appreciable time after the withdrawal of the exciting stimulus.

the bones of the hand, and from that moment the modern science of X-ray work in surgical and medical practice came into being. Röntgen further showed that by the use of screens painted over with fluorescent materials it was possible to produce visible images of bodies by means of X rays without having recourse to the employment of photographic plates.

A Crookes tube is a vacuum tube in which the exhaustion of the air has been carried to an excessively high degree—viz., about one millionth of the atmospheric pressure. It is so named because Sir William Crookes first interpreted the phenomena to be observed in such an apparatus. It differs from an ordinary vacuum tube or Geissler tube in its appearance when electrically excited. At low degrees of exhaustion a tube of that kind appears filled with glowing gas during the passage through it of an electrical discharge, but the highly-exhausted tube shows no such glow. It exhibits instead a peculiar fluorescence of its walls, which is of a pale yellowish-green colour when the tube is made of soda glass, and is blue when lead glass is employed. The fluorescence is caused by a bombardment of the glass by streams of negatively-charged gaseous particles propelled with enormous velocity from the kathode.

These streams of negatively-charged particles constitute the kathode rays, which were shown by Lenard to be able to pass through thin layers of aluminium, and to exist in the air immediately outside the window of his tubes. The effect of the high exhaustion in a Crookes tube is to diminish the quantity of residual gas in the tube to such a degree that the particles set in motion at the kathode are able to move in straight lines for a considerable distance, and to strike the glass wall of the tube without obstruction or retardation through collision with one another. Thus, the higher the vacuum, the more freely can they travel when once set in motion, and the longer is their "mean free path." In tubes of low vacuum their movement is obstructed and arrested before they can travel the required distance, and the luminosity of the gas in such tubes is the result of the energy imparted to it by the collisions and consequent arrest of the negative particles. It was shown by Crookes that when the vacuum in the tube is sufficiently high the particles are propelled in straight lines from the surface or surfaces of the kathode, and continue to travel in straight lines until they strike an obstacle, such as the walls of the tube itself, or of

any body intentionally enclosed in the body of the tube so as to lie in the path of their movements.

Crookes' presidential address to the Institution of Electrical Engineers in 1891 should be read by all who wish to trace the history of the work which led up to the discovery of X rays.*

The particles moving from the kathode or kathode stream are not fragments of the metallic kathode itself, although this view was advanced by certain Continental observers. Before the year 1891, Crookes had shown that this was not the case, and he maintained that they were derived from the residual gas in the vacuum tube, but were in a peculiar "ultra-gaseous" condition, and he described them as representing a "fourth state of matter," or matter in radiation. He uses the following remarkable words: "The molecules . . . at these high exhaustions under electric stress have become exalted into an ultra-gaseous state, in which very decided properties, previously masked, come into play." It has been shown quite recently that the particles concerned in the kathode stream are not atoms or molecules, but are in a much finer state of subdivision, probably having a mass of about one-thousandth part of the mass of an atom, and the word "electron" is used to signify them. The kathode rays are therefore to be regarded as a stream of negatively-charged electrons moving with an enormous velocity, comparable with that of the speed of light. They are therefore not rays in the ordinary sense of the word. In virtue of their nature as electrically-charged and moving particles they are acted upon by a magnetic pole, and can be deflected from their course by its means. It has been proved that X rays are not influenced by a magnet, and this is evidence that X rays differ from kathode rays in not being composed of electrically-charged particles.

When the kathode rays strike any solid object this motion is arrested, and it is their sudden impact or arrest of motion which gives rise to the X rays. The X rays are true rays—that is to say, they are radiations or disturbances in the ether—and they thus differ fundamentally from the stream of negatively-charged electrons which constitutes the kathode rays.

In some of the forms of tube devised by Crookes for showing

* See *Journal of the Institution of Electrical Engineers*, 1891, or the *Electrician*, January, 1891.

his effects the kathode rays strike upon the glass wall of the vacuum tube, or upon bodies enclosed within it, and produce a fluorescence, and at the point where they strike they generate X rays. In the earliest X-ray tubes, also, the kathode stream was caused to fall upon the wall of the bulb, but these tubes were not able to cast sharply-defined shadows, because the rays were emitted from large and irregular surfaces.

X rays differ from the ethereal radiations which constitute light in consisting of irregular solitary impulses, whereas light radiations are even undulations following one another in a regular sequence.

147. **Properties of X Rays.**—X rays have the property of discharging an electrified body by ionizing the air surrounding it. With X rays discharge takes place whether the body be positively or negatively electrified. X rays also impart a positive charge to bodies on which they fall, though this is not easy to demonstrate. K. Hahn* states that there is a breaking down of some valency bonds under the influence of the rays, setting free both ions and electrons, and the latter may be projected, leaving the body positively charged. Hard rays are more effective, and the phenomenon is most marked in bodies of high atomic weight. X rays excite fluorescence in certain substances, especially in the platinocyanides of barium and potassium, in some uranium compounds, as uranium oxy-fluoride, in zinc sulphide (Sidot's blende or hexagonal blende), and in calcium tungstate. They act upon sensitive salts of silver, producing the same effect as that of light, and they penetrate opaque bodies, although these are not all equally transparent. In a general way it may be said that bodies are opaque to X rays in proportion to the atomic weights of the elements composing them; thus, aluminium with an atomic weight of 27 is more transparent than sulphur, whose atomic weight is 32, and platinum and lead, whose atomic weights are very much greater, are also very much more opaque to X rays than the former elements. X rays have been shown by E. Marx to travel with the velocity of light, and Barkla† has recently proved that X rays can be polarized, and therefore that they resemble ordinary light in consisting of progressive disturbances taking place transversely to the direction of their propagation.

* *Ann der Physik*, No. 11, 1905.

† *Electrician*, February 24, 1905 (abstract).

Under different conditions vacuum rays of different qualities are emitted by an X-ray tube, and this is made use of in practical work to obtain rays of the degree of penetration best suited for different branches of X-ray work.

Any X-ray tube in action emits rays of different degrees of penetrating power, and the output of a tube can be filtered, as it were, by causing it to pass through a layer of some substance which is capable of absorbing the less penetrating rays, while allowing the more penetrating rays to pass. Silver and certain allied metals show anomalies in their absorptive action upon X rays, which makes them appear to absorb rays from hard and soft tubes to an equal degree.

148. **Production of X Rays.**—The essential parts for the production of X rays are two in number—a Crookes tube, suitably modified, which will be spoken of as an X-ray tube, and an electrical apparatus capable of supplying currents at the potential necessary to excite the tube to action.

The instruments in use for obtaining the high electromotive forces needed to excite an X-ray tube are the induction coil, the statical machine, and the high potential transformer. Of these, the induction coil is the most generally used at the present time.

The statical machine has certain advantages, but it has the one great disadvantage of not being portable except in the smaller sizes, and these have not yet shown themselves equal to the coil. It is therefore not possible to use it for cases requiring the application of X rays except in the consulting-room.

One of the special advantages of the statical machine consists in its simplicity. Whereas a coil requires accumulators to drive it—and the recharging of these accumulators may be a matter of great difficulty in remote or country places—the statical machine is a self-contained electrical apparatus capable of generating the necessary electromotive force by itself whenever its handle is turned. It also gives a steady radiation with X-ray tubes, which is agreeable to the eye with screen work. For photography it is slower than the induction coil, though perhaps it gives finer focus in the pictures, because the discharges of the statical machine are unidirectional.

The Tesla coil, which affords a ready means of obtaining currents of high potential, is not very suitable for exciting X-ray tubes. In the first place, it gives an alternating current,

but the real objection is that its discharges are high-frequency discharges, and high-frequency discharges behave in a peculiar manner inside a vacuum tube. Strange to say, it is very difficult to confine them to the leading-in wire, so as to deliver them where wanted at the surface of the kathode. They have a strong tendency to escape into the vacuum tube from the stem or support of the electrodes, in order to pass from the metallic conductor into the gaseous one. If the stems be protected by a glass tube, as is usual, they tend to puncture this, and opposite the point at which they so puncture the glass stem they quickly heat the wall of the tube and cause it to crack. On this account the use of the Tesla coil is now almost totally neglected in X-ray work.

The usual size of coil for X-ray work is a twelve-inch coil. Fair work may be done with smaller instruments, but in practical work it is found that the more powerful the coil the better will be the results, and the shorter will be the necessary period of the exposure. A larger coil also permits of greater latitude in the choice of a tube, for a coil of low power may not be able to excite tubes of high resistance. On the Continent eighteen-inch coils are not infrequently used.

When current from an electric-lighting supply is not available a small gas-engine and dynamo is to be preferred (§ 50). The transportation of accumulators to a source of electricity at a distance for recharging is out of the question for heavy hospital work. The dynamo plant, once laid down, will remain a serviceable source of electricity, and with a set of accumulators it would suffice to run the engine once or twice a week to keep the battery in a fully-charged state.

A convenient pressure of supply in such a case would be fifty volts. At this pressure the strain upon the interrupting devices is not great, and these therefore work better and last longer than with higher pressures. A pressure of fifty volts is sufficient to permit of rapid interruptions and a steady light upon the fluorescent screen.

149. **High Potential Transformers for X-ray Work.**—These have already been considered in the preceding chapter, and although they have not yet come into such general use for X-ray work as the Ruhmkorff coil, it is probable that they will eventually be preferred in places supplied by alternating current. Fig. 146 shows the appearance of the transformer cabinet of

M. Gaiffe arranged for X-ray work, and Fig. 147 shows on a larger scale the valve tubes arranged in shunt to the X-ray tube, and the milliampèremeter in series with it. In Fig. 148 a diagram of the circuits of the apparatus is represented. The

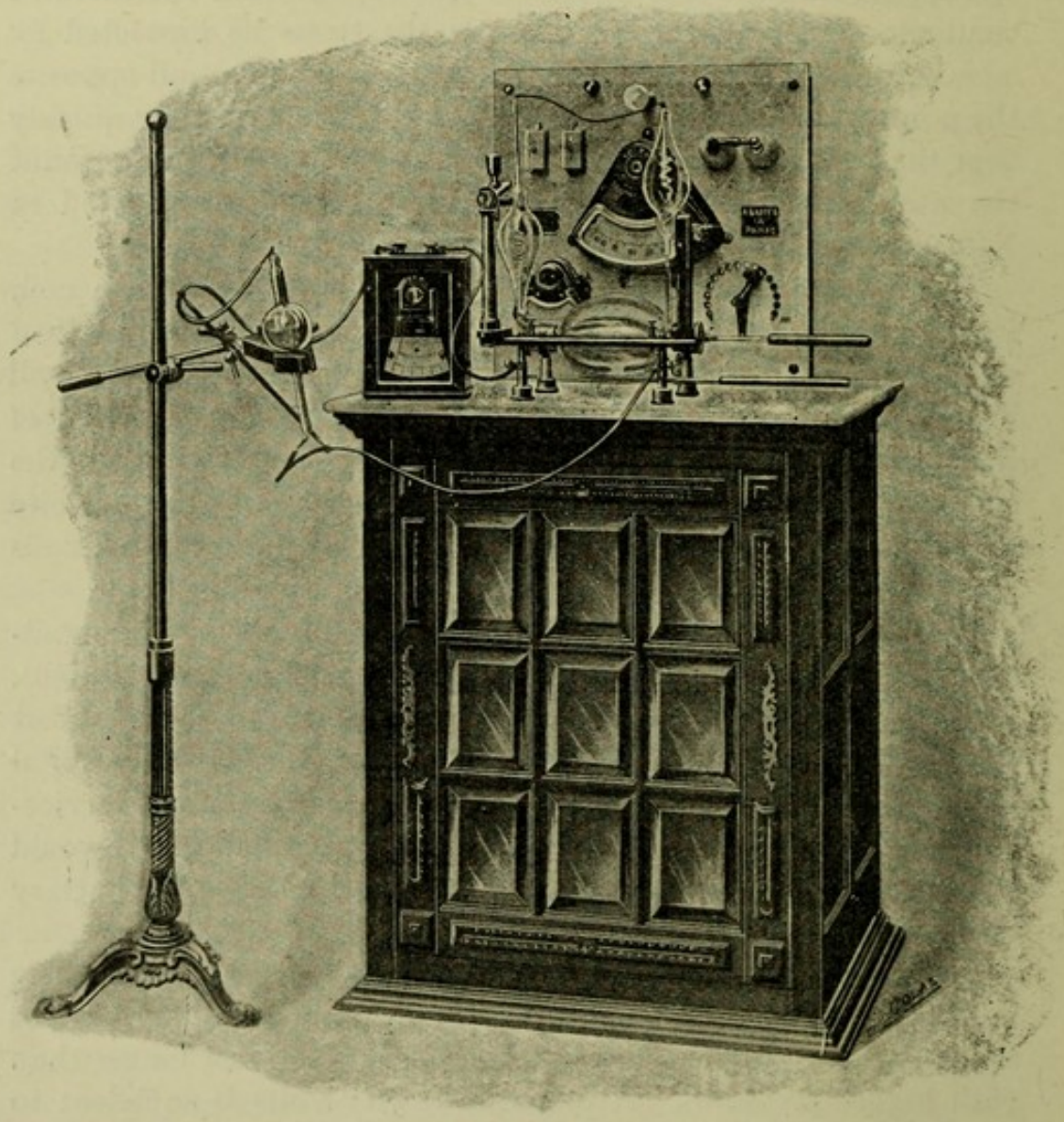


FIG. 146.—GAIFFE'S TRANSFORMER ARRANGED FOR X-RAY WORK.

condensers seen in shunt to the transformer windings are to prevent the formation of high-frequency oscillations, which tend to break down the transformer resistance. The other condensers in series between transformer and valve tube are to

reduce the output of current, in order to protect the X-ray tube and valve tube.

150. **X-ray Tubes.**—The design of the special form of Crookes tube for X-ray work was the work of Professor Jackson, of King's College, London, who contrived a tube with a platinum target fixed in such a position as to receive the concentrated bombardment from the kathode. The X rays in this form of

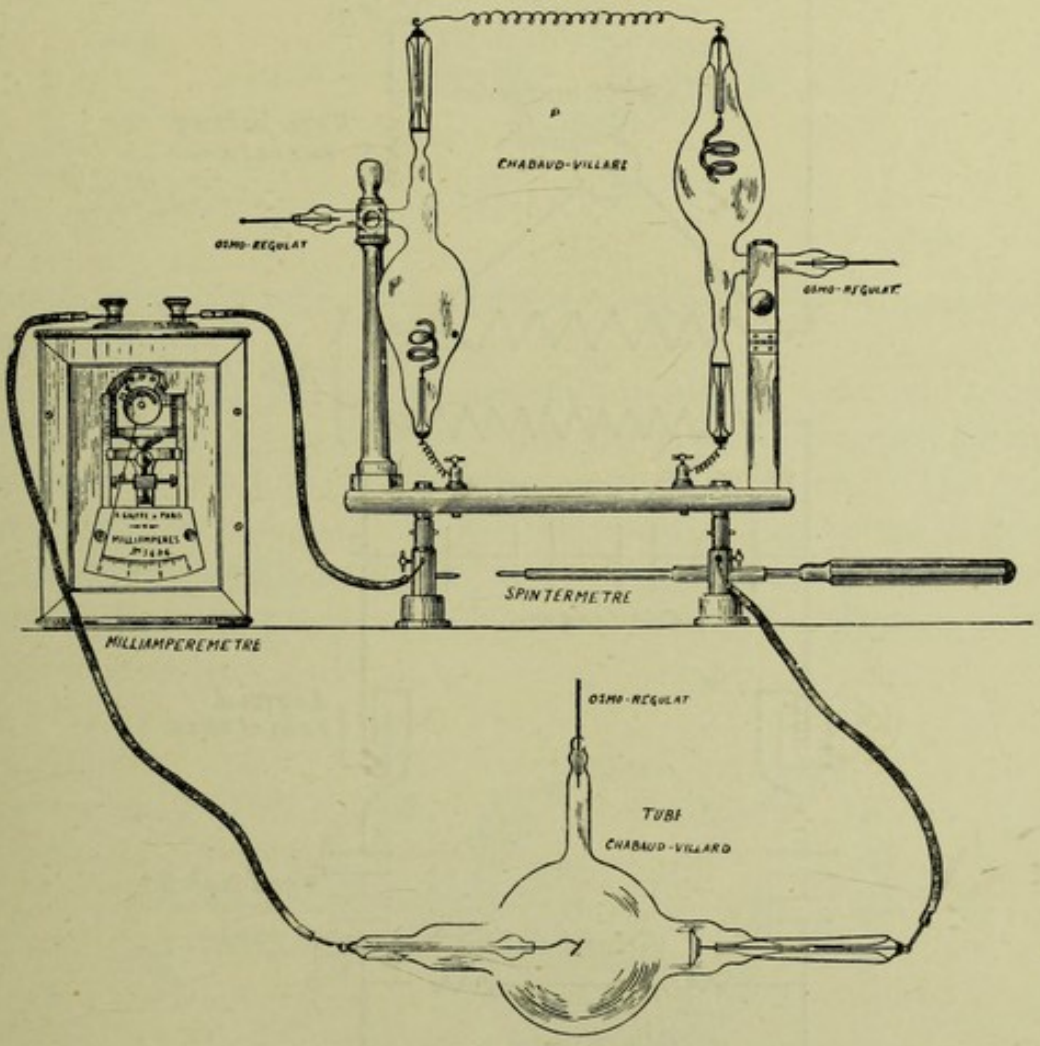


FIG. 147.—ARRANGEMENT OF VALVE TUBES, MILLIAMPÈREMETER, AND X-RAY TUBE IN GAIFFE'S APPARATUS.

tube are emitted from a small focus on the surface of the platinum target, and the rays therefore cast much sharper shadows than if they come from the general surface of the glass wall of the tube. The platinum target or anti-kathode is placed nearly, though not exactly, at the focus of the kathode in an oblique position (Fig. 149). The anti-kathode acts also as the anode of the system. The kathode is made of aluminium, because this

metal does not become disintegrated under the action of the discharges. Most metals, when they form the kathode in a vacuum tube, are thrown off in minute particles, and are de-

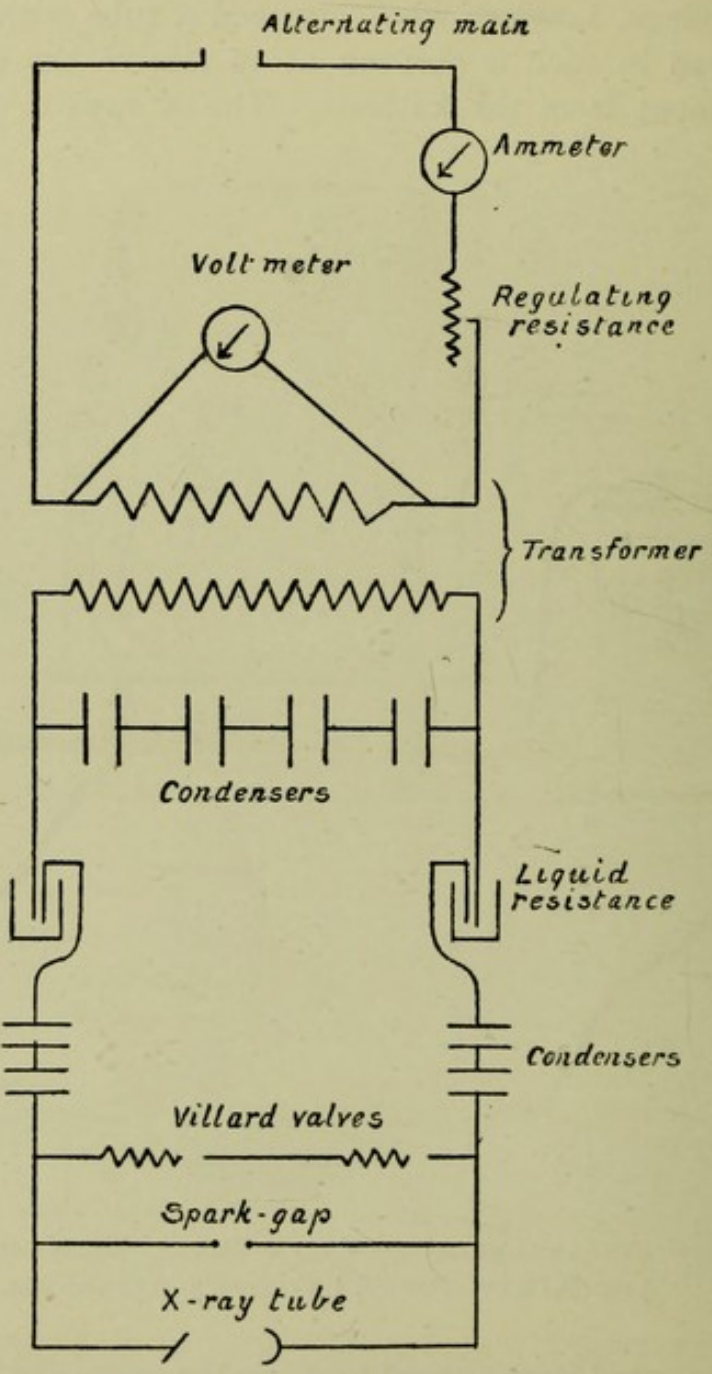


FIG. 148.—SCHEME OF THE CIRCUITS IN GAIFFE'S APPARATUS (AFTER BELOT).

posited as a film upon the adjoining parts of the wall of the tube.

The target or anti-kathode is fixed obliquely to the axis of the tube, in order that the beam of Röntgen rays may be directed

to one side, and hence may be readily thrown upon the object to be investigated.

Fig. 150 shows a form of the Jackson tube which has been widely used. In it one may see the cup-shaped kathode, the obliquely-placed target or anti-kathode of platinum, and a third terminal which is usually connected to the anti-kathode by a

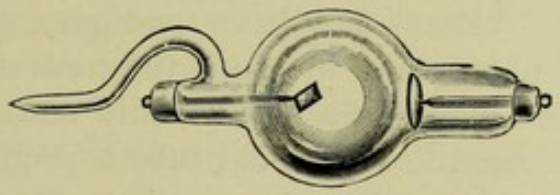


FIG. 149.—ORIGINAL MODEL OF JACKSON'S FOCUS TUBE.

wire outside the tube, and which is thought to act in some way as a regulator.

During use an X-ray tube becomes gradually more and more difficult to excite, and many tubes have been discarded owing to their vacuum having become so high as to resist the full power of the coil used for exciting them. The actual degree of vacuum which is best in a tube will depend upon the electromotive force which is available for exciting it. Thus a tube

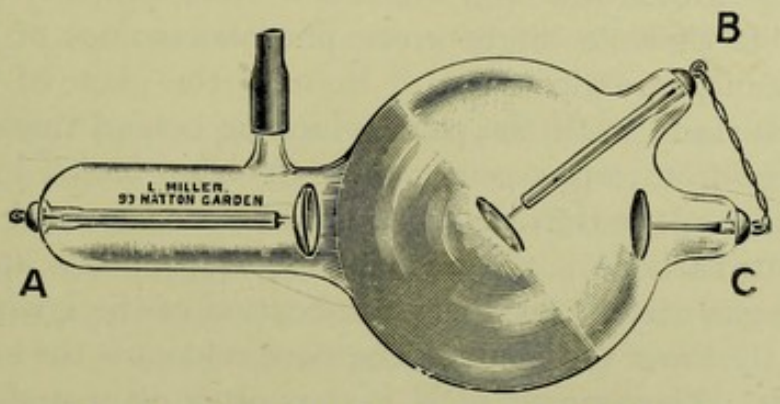


FIG. 150.—COMMON FORM OF X-RAY TUBE.

A, Kathode; B, anti-kathode or target; C, anode or third terminal.

which is too high for a small coil will serve admirably for another of greater power. There are, therefore, fairly wide limits of vacuum within which X-ray effects can be produced. The higher the vacuum in the tube, the stronger is the electromotive force necessary to work it, and the greater is the power of penetration of the X-ray radiance emitted. At the high vacuum

the velocity of the bombardment is greater, by reason of the higher electromotive force needed to excite the tube, and the X rays generated are more sudden and more penetrative, as the kathode rays then reach a maximum speed, and their stoppage at the target is more sudden.

The words " soft " and " hard " are commonly used to designate tubes of lower and of higher resistance respectively. When a tube is " hard " its rays may have too high a penetration, and will then give a photograph in which the contrasts between the bones and the soft tissues are insufficiently marked.

The increased resistance of an old tube is probably due to the absorption or " occlusion " of some of its gaseous contents by the wall of the tube, by the electrodes, or by finely disintegrated particles which are gradually thrown off from the electrodes, and adhere to the glass of the tube. This ageing is especially promoted if the current is allowed to pass through the tube in the wrong direction. Care should therefore be taken to avoid this. A tube that has been carefully used gradually acquires a violet tint in the hemisphere corresponding to its effective side, by reason of chemical changes in the thickness of the glass; but a tube allowed to work improperly becomes blackened more or less all over, from a metallic deposit upon its inner surface.

The appearance of a tube which is working properly is characteristic. It shows a bright green phosphorescence of the glass in the hemisphere which lies in front of the plane of the anti-kathode surface, while the parts which lie behind this plane are almost free from any green colour. A faint bluish luminosity in the gas itself within the tube may be seen around the back of the anti-kathode if the vacuum is low, and this appearance of visible gas may be used as an indication of the quality of the tube, for the lower the vacuum, the more evident is the luminosity of the gas. The amount of X rays is often estimated from the brightness of the fluorescent hemisphere if the room is dark. In daylight the fluorescence is easily overpowered. Though fluorescence goes hand in hand with X-ray production, the glass may fluoresce when the vacuum is so low as to be almost useless for X-ray work, but in such cases the true state of affairs is easily recognised by the low resistance of the tube. If the current through the tube is in the wrong direction, no hemisphere of fluorescence is recognisable.

As it is practically impossible to find a substance hard enough

to stand the full effects of a sustained bombardment by the kathode stream concentrated upon one point on its surface, the platinum anti-kathode is intentionally placed at a little distance beyond the actual focus. Nickel anti-kathodes are now often employed.

The size of X-ray tubes has progressively increased since their introduction. It is found that a large tube ages less rapidly than a small one, and also varies less in its condition during the period of an X-ray application.

When high-speed interrupters are used the discharges follow each other in such rapid succession that the tubes are likely to become overheated. Even with moderate work the anti-kathode often becomes heated to redness during an exposure, and its vacuum may be inconveniently changed thereby. To obviate these difficulties tubes have been made with special arrangements. Anti-kathodes backed by an extra mass of

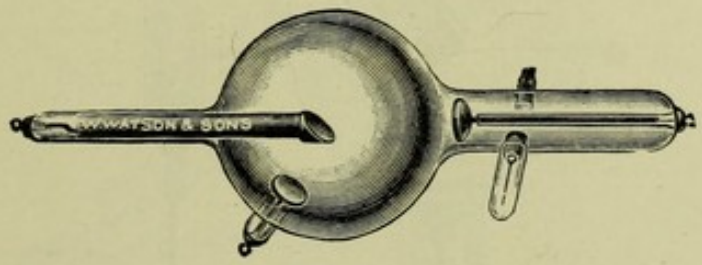


FIG. 151.—GUNDELACH'S TUBE, WITH HEAVY ANTI-KATHODE.

metal (Fig. 151), or water-cooled anti-kathodes (Fig. 152), are employed. With the electrolytic breaks of Wehnelt and Caldwell such tubes are almost indispensable.

At the present time there is a tendency to return to simpler forms of X-ray tube, and to employ only such tubes as have a means of regulating the vacuum.

151. **Regulation of Vacuum.**—The inconveniences arising from the gradual ageing of X-ray tubes when in use have led to the introduction of various contrivances for lowering the vacuum if it becomes too high. Some of these depend upon the inclusion in a side tube of a chemical compound, such as caustic potash, which gives off vapour when warmed. Another method of temporarily lowering a tube is to heat it with a spirit-lamp flame or before a fire. Prolonged baking in an oven at a high temperature will often lower the resistance of a tube more or less permanently.

A simple method which may be used to lower the resistance of a high tube is the following : A sheath of damp lint or cotton-wool is applied to the kathodal end of the tube. It should extend along the glass to a point level with the surface of the kathode, and should also touch the leading-in wire. It gives a negative charge to the outside of the glass, and probably promotes the movement of positive ions to the region round the kathode. The effect of this device upon the apparent resistance of the tube is very marked, and its use will often permit of the employment of a tube which otherwise would be too hard to work with.

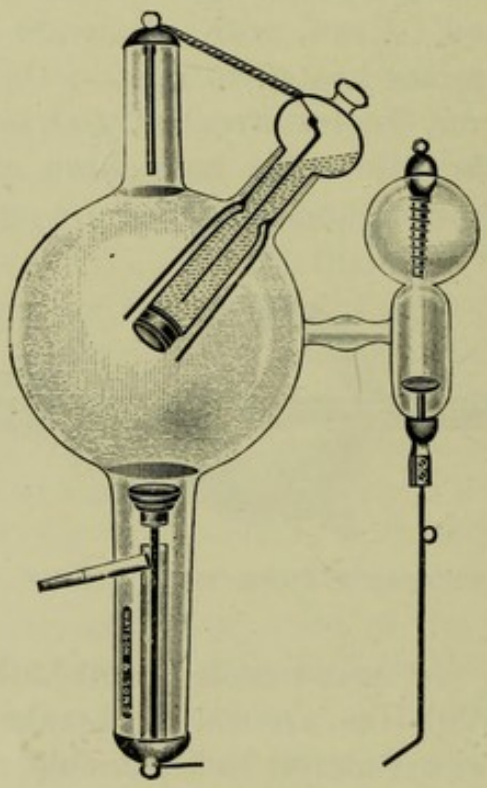


FIG. 152.—TUBE WITH WATER-COOLED ANTI-KATHODE AND SIDE TUBE FOR REGULATION.

Another tube-regulation method is the use of an accessory side bulb to the tube with terminals between which sparks can be passed at will. The special terminals of the side tube are constructed of some material which will emit gas when heated by the passage of sparks, and the gas so disengaged enters the main body of the tube and lowers the vacuum. Fig. 152 shows an arrangement of this sort. The long hinged wire can be so placed that a spark may pass to it whenever the vacuum becomes too high, and in this way the tube is made self-regulating. These tubes need care in management. When they are new,

the effect of the passage of a spark through the side tube is apt to be greater than is desired, and the vacuum in the tube may easily be reduced too much; and with age the side tube fails to emit gas with sufficient readiness

The best method of reducing the vacuum depends upon the power possessed by platinum of becoming permeable to hydrogen gas when heated to a red heat. A thin-walled tubular wire of platinum closed at its outer end is sealed into a side branch of the X-ray tube. It projects outwardly for a distance of about two inches. If a spirit-lamp flame is brought into contact with it, hydrogen from the flame is absorbed by the metal, and enters

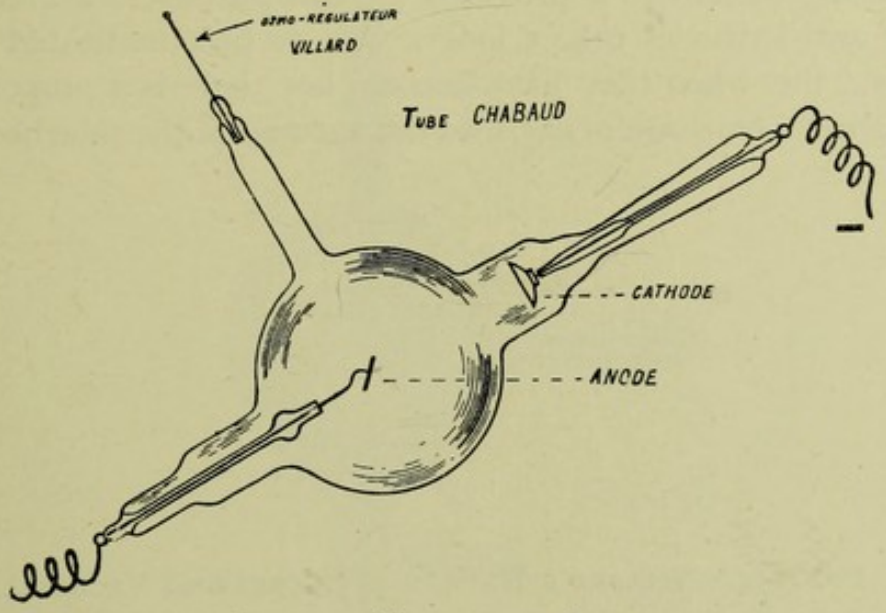


FIG. 153.—CHABAUD TUBE WITH OSMO-REGULATOR.

the tube. This is known as the osmo-regulator of Villard. It is shown in Fig. 153.

It is said that by a modification of this device the opposite effect can be produced, and the vacuum within the tube can be raised if necessary. To effect this the wire is enclosed in a loose sleeve of platinum open at both ends. When this sleeve is held in the flame it protects the wire from the gases of the flame, and is traversed by a flow of atmospheric air. Under these conditions there is a tendency for gas to diffuse outwards from the inside of the tube. This is a slow and less certain process than that for lowering the vacuum, and the tubes should not be made too low.

The osmo-regulator of Villard is greatly superior to all the other methods of vacuum regulation. It is poor economy to

spend money on a tube without the osmo-regulator. The best tubes for general work at the present time are the simple tubes of Chabaud. In these the anti-kathode is of thick platinum, and the tubes work well with the anti-kathode at a red heat—in fact, the tubes are then working normally, and under these conditions their vacuum does not fall, and a source of trouble is thus completely obviated. Unless these tubes are over-driven their vacuum tends to rise slowly when they are running with a red-hot anti-kathode, but the vacuum can be kept constant for very long periods of time by applying a flame to the osmo-regulator at intervals. A spirit-lamp or gas-jet on a long insulated handle is provided for this purpose. Tubes with heavy anti-kathodes take a longer time to become heated when working, but when they have become hot there is a proportionately greater emission of gas, and the vacuum of the tube becomes

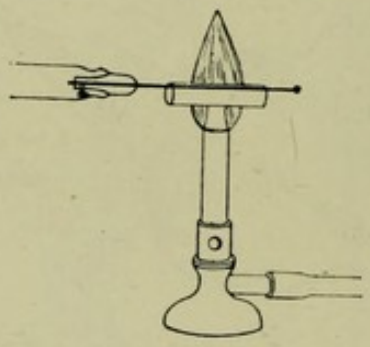


FIG. 154.—VILLARD'S METHOD OF INCREASING VACUUM

lower than would be the case with an ordinary anti-kathode. The advantage of the heavy anode tube is that it stands a longer run; the disadvantage is that when its limit is passed the vacuum may be lowered for an extra long time.

Tubes with water-cooled anti-kathodes have certain advantages, as they will stand a heavier current than tubes of other types for a short time. They cannot, however, be properly worked in all positions, for one cannot rely on the water being in contact with the target when this is at a higher level than the water. In any case these tubes require careful handling.

A good X-ray tube deserves the most careful treatment. A valve tube and a milliampèremeter should always form part of the circuit, as one can then see how the tube is behaving, and the inverse currents which tend to injure the tube and to blur its definition are stopped out.

Tubes of the Chabaud pattern, when new, should be worked gently with a current of about 0·4 milliampère, until it is seen that they can stand more. The aim should be to pass as much current as the tube can take without a fall in its resistance. If the pointer of the milliampèremeter shows that the current through the tube is rising, it indicates that the vacuum of the tube is getting lower, and as it is troublesome to readjust a tube when too low, it is better not to let the vacuum get too low.

When the resistance of the tube is seen to be gradually rising,

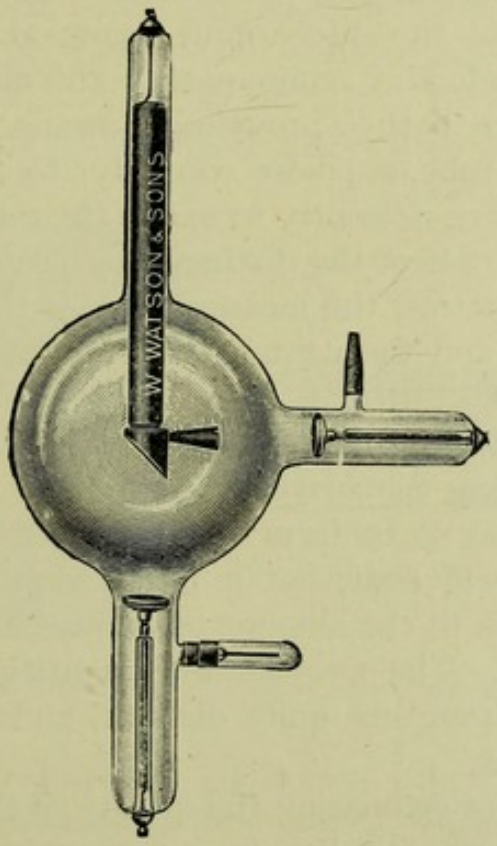


Fig. 155.—Bi-kathodal Tube.

it is working normally, and as the resistance of the tube increases and the current falls off, a flame can be applied to the osmo-regulator, and the needle of the milliampèremeter watched till it indicates that a proper magnitude of current is again traversing the tube.

Fig. 155 shows a tube which may be used upon the circuit of a high potential transformer. The connections are made to the two kathodes. One kathode stream strikes the anti-kathode upon its surface and generates X rays, while the reversed current sends its kathode stream into the hollow cone seen at

the side of the anti-kathode, and the X rays produced by their impact are absorbed, and do not complicate the effects.

152. **Equivalent Sparking Distance.**—The resistance of a tube is usually specified in terms of the length of air-gap which offers an equal resistance, when arranged as an alternative path in parallel to the tube. If the points of the discharger of the coil are gradually brought together while the coil is in action supplying an X-ray tube, a stage is reached when the discharge of the coil sparks across through the air between the discharging points instead of passing through the tube. With different tubes the distance apart of the discharging points at which this takes place varies considerably; consequently, this method of measuring the "alternative path" provides a means of estimating the resistance of a tube, or, more correctly, the magnitude of the electromotive force necessary to excite the tube.

If the sliding rods of the discharger are suitably graduated in inches or centimetres, the measurement of the alternative path is made easier, and the contrivance has been called a spintermeter or spark-measurer.

153. **Comparison of Tubes.**—The length of the equivalent sparking distance enables one to compare the resistances of X-ray tubes, and so to form an idea as to the quality of the radiation they will emit, but it is far from being sufficient to act as a guide as to the amount of X rays emitted at any particular moment. The two factors, quantity of radiation and quality of radiation, are quite distinct, and must not be confounded together.

Another way of estimating the quality of the X rays, or their penetrating power, consists in a comparison of the relative opacities of two or more bodies of different densities with the rays under examination. This is done in a rough and ready way when the image of the hand is viewed on the fluorescent screen, and the blackness of the shadow cast by the bones is compared with that thrown by the soft parts. When the bones appear relatively dark the rays of the tube are said to have a low degree of penetration, and when they appear light, and hardly darker than the soft tissues, the tube is said to be giving rays of high penetration.

L. Benoist has invented a simple instrument, the radiochromometer, for observing the relative opacities of dissimilar bodies, using for comparison silver and aluminium. Professor

Röntgen had previously designed a similar apparatus for comparing aluminium with platinum. Benoist's instrument consists of a disc of aluminium so cut away as to form a series of twelve sectors arranged in steps of different thickness, from 1 to 12 millimetres, around a centre. The aluminium of the centre of the disc is removed and replaced by a circular piece of sheet silver 0·11 of a millimetre in thickness. The image of the whole combination is viewed by a fluorescent screen, and the amount of fluorescent effect transmitted through the silver is compared with that coming through different thicknesses of aluminium. Some of these latter appear brighter and some darker than the silver, and the penetration of the rays is deduced from observing which of the thicknesses of aluminium is most

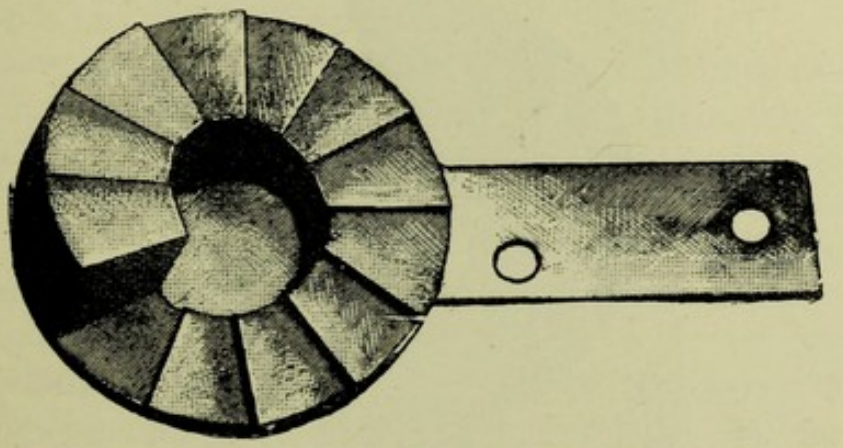


Fig. 156.—Benoist's Radiochromometer.

closely comparable to the silver. The more penetrating the rays, the more do they penetrate the aluminium. With a tube of high penetration the ninth or tenth thickness of aluminium throws a shadow comparable with that of the silver. With a low tube the thinner layers numbered two or three do so (Fig. 157).

Other instruments in the nature of fluorescent screens backed by variable thicknesses of lead foil can be used in the same way.

Benoist's instrument and a similar device of Dr. Walter's measure the penetrating quality of the rays. To measure the quantity several procedures have been tried. Holtzknecht used a chemical substance, the colour of which grows gradually darker with exposure ; a disc of this material is exposed simultaneously with the patient, and the change in colour of the chemical is compared from time to time with a standard, and the effect can thus be estimated. This apparatus has fallen

into disuse, but it is likely to be revived in an improved form, and meanwhile it has given rise to a new unit expressed by the symbol H. 1.H is one-fifth of the amount of radiation which the normal skin will stand without developing a dermatitis.

A solution of iodoform in chloroform has been proposed by Freund for measuring the quantity of X-rays. Here, too, there is a difficulty, for the solution is unstable unless both ingredients are of the highest purity, and ordinary daylight acts on it in the same way as X-rays, setting free iodine with the production of a pink colour.

Sabouraud and Noiré have employed pastilles of platino-

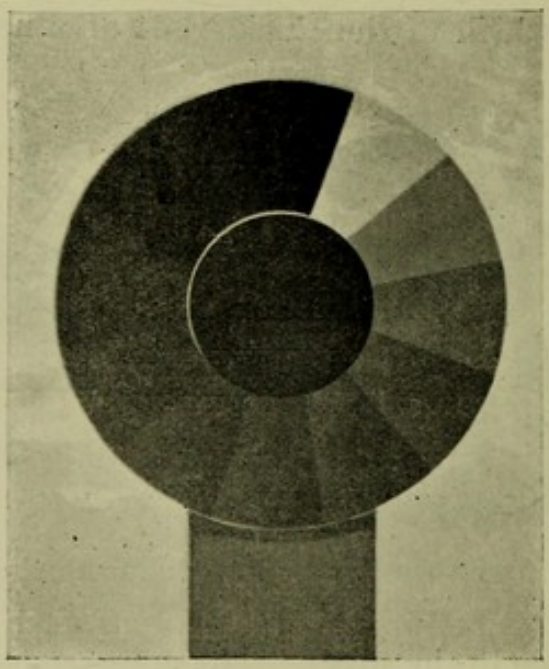


FIG. 157.—SCREEN IMAGE OF BENOIST'S RADIOCHROMOMETER.

cyanide of barium for obtaining indications of the quantity of X-rays. This compound, as is well known to all workers with fluorescent screens, undergoes a gradual change when exposed to X-rays for some time. It loses its lemon-yellow colour and becomes brown, and this colour change is used as a means for measurement. If a pastille of the platinocyanide be exposed to X-rays at a distance midway between the anti-kathode of the tube and the surface of the patient, a decided brown colour is produced at about the time when the skin has received the maximum exposure which can be borne without exciting dermatitis (5.H). In the treatment of ringworm, this represents the proper dose, and causes a loss of hair over the exposed part,

thus indirectly curing the disease. A fresh growth of normal hair commences in due course if this degree of exposure has not been exceeded. This mode of measurement has been found satisfactory for the safe treatment of ringworm, but obviously it has no great applicability to X-ray measurement in general.

Inasmuch as Sabouraud's pastilles respond to the X rays which actually fall upon them, and may therefore be regarded as measuring the precise effect which it is desired to measure—namely, the quantity of X-rays falling upon a given area of the patient—they are superior to any indirect measurement, such as the measurement of the current through the X-ray tube; for to assume that the X-rays emitted by a tube are directly proportional to the current through the tube introduces new difficulties, although it is probable that such a measurement of current is not untrustworthy as a guide.

A photographic method depending upon a change of tint in a sensitive paper has been brought forward lately, but it has the drawback of not affording the required information until after the X-ray exposure, and then only by development in a dark room. The same objection, that the information comes at the end of the operation, applies, though with less force, to Sabouraud's method.

154. **Measurement of Current through the X-ray Tube.**—A milliampèremeter can be used to measure the current passing through the X-ray tube, and the production of X-rays bears a close relationship to the current so measured. D'Arsonval* has shown that photographs taken with different currents through X-ray tubes were identical when the times of exposure were so adjusted that the figures obtained by multiplying currents by time were equal. For example, three exposures were made : one with 0·45 milliampère for 45 seconds, one with 1·0 milliampère and 20 seconds, and a third with 1·25 milliampères and 15·5 seconds. By multiplying the figures for the time and the current, the numbers in milliampère-seconds are as follows : For the first, 20·25 ; for the second, 20·00 ; and for the third, 20·47. The photographs produced were of equal density.

In order to measure the effective current through an X-ray tube with accuracy it is desirable that currents in the wrong direction should be eliminated. This is necessary because it would be a misleading operation to measure currents of which some un-

* *Comptes Rendus*, May 9, 1904.

known proportion was ineffective towards the production of the X-rays.

The Villard valve-tube arranged in series with the X-ray tube (Fig. 158) affords a simple means of ensuring that the current through the tube shall be unidirectional, and experiments with the oscilloscope (§ 119) show that the rectifying action of the Villard tube is remarkably complete.

When a direct current galvanometer is connected up in the circuit of an X-ray tube without the use of a valve-tube, deflections will generally be obtained, and these represent the difference between the currents which are passing in the two opposing directions. Sometimes, especially with low tubes, the deflection indicates that the inverse current is greater than that producing X-rays, while in other tubes the deflection indicates a predominance of current in the right direction. In any case, the insertion of a valve-tube alters the readings from those obtained without it in such a way as to show that its effect in stopping the inverse impulses is important for purposes of accurate measurement. In experimenting with three tubes, both with and without a valve-tube in the circuit, the following readings (milliampères) were obtained :

Tube.	Without Valve.	With Valve.
1	0·9	1·0
2	0·25	0·4
3	0·1	0·3

All these were selected tubes which gave fair deflections in the right direction without a valve-tube. Tubes may easily be found in which the wrong direction of current predominates, but with the use of a valve-tube this changes into a flow in the right direction.

An ordinary medical milliampèremeter of the D'Arsonval pattern serves very well for use in the tube circuit. Slight modifications in the insulation of these instruments are now being made in order to protect their windings more fully from the risk of injury by sparks passing between their windings, and small condensers are also fitted to some of them. Messrs. Gaiffe make a special milliampèremeter of large size and fine quality for X-ray work, and Mr. Schall supplies a convenient instrument which can be attached to the support of the tube-holder (Fig. 158), and is graduated in tenths to 3 milliampères. This is the most generally convenient milliampèremeter in commerce at the present time.

The Villard valve-tube acts best when its vacuum is at such a stage as to show a violet luminosity and no green fluorescence, and it should accordingly be provided with an osmo-regulator, or some other contrivance, for reducing its resistance when this has become too high through use. It may seem high when it is not so if working in series with a very high X-ray tube.

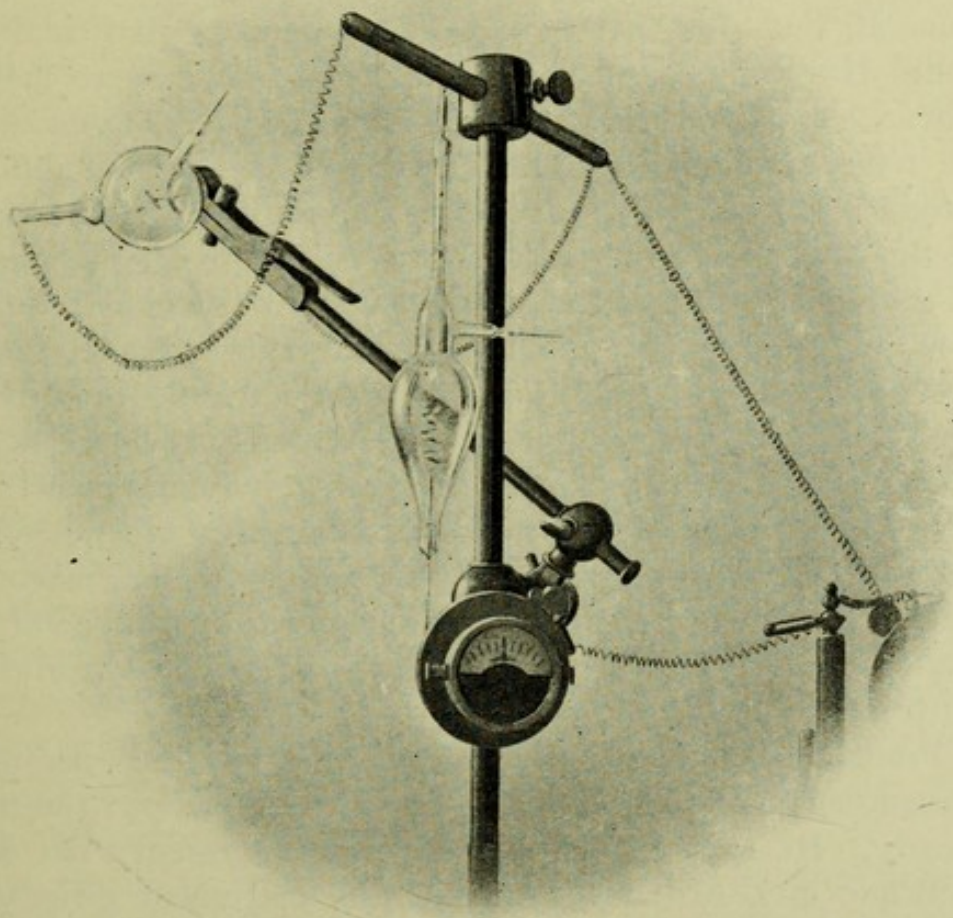


FIG. 158.—X-RAY TUBE STAND, SHOWING DISPOSITION OF MILLIAMPÈRE-METER AND VALVE TUBE.

The current passes from the upper end of the valve-tube by a fine wire to the end of the nearer cross-arm, and so on to the X-ray tube, and from the other end of the tube it returns to the other cross-arm and so back to the coil.

The usual current through an X-ray tube ranges between 0·2 and 1·0 milliampère. With larger currents the tubes are likely to become overheated. A current between 0·5 and 0·1 milliampère is sufficient for good average work.

It is probable that one reason for doubt as to the degree of

reliance to be placed upon the galvanometer readings in X-ray measurement is an uncertainty as to the efficiency of the Villard tube. In view of the erratic character of readings taken without a valve it was clear that the whole position rested upon the efficacy of this link in the circuit, and it was by no means easy until quite lately to offer any satisfactory evidence upon this point, which was rendered the more uncertain because the degree of vacuum differs in different valve-tubes, and changes with use. Thus one could call in question not only the efficiency of Villard tubes in general, but also that of any one tube at a particular time. Until this point could be settled it was not easy to meet the obvious objection that the galvanometric readings could not be relied on, and that they measured an artificial difference produced in the valve-tube, and were an indication of the efficiency of the valve rather than of the current passing through the X-ray tube. Fortunately, the behaviour of the valve-tube can now be tested by the oscilloscope, and it is found to stand the test remarkably well, and to show that as a rectifier of currents in an X-ray tube circuit it behaves with remarkably high efficiency.

Some may perhaps doubt whether a milliampèremeter can give correct indications with a current which has the form of intermittent impulses separated by periods of no current, but under the ordinary conditions of X-ray work with a good interrupter the readings of the galvanometer are steady and may be trusted.

Professor Wertheim Salomonson, in a recent paper on the measurement of currents in X-ray circuits, has put the matter clearly. He says: "The milliampèremeter constructed on the principle of D'Arsonval's moving coil instrument gives us the mean value of the quantity of electricity flowing through the focus-tube. If the inertia of the moving-coil is great enough, it gives a steady deflection even with a unidirectional but rapidly varying current so long as the mean value of the current does not change." He then goes on to point out that if the current be supposed to consist of 20 discharges per second, and this registers 1 milliampère, that 40 discharges per second of the same form and duration would read 2 milliampères, and that it would give the same reading if each discharge were made twice as strong as at first, but the number per second were still kept at twenty; and he asks whether the X-ray production of the 20 strong discharges would be the same as that of the forty weak ones,

and adds very properly that this question cannot be answered by mere reasoning.

We may assume that the current going through the X-ray tube when a Villard valve is used is practically or even absolutely unidirectional, and therefore that its mean value admits of measurement by a direct current galvanometer, and it is at this point that the real crux of the situation is to be found. Are we at liberty to assume that the production of X-rays is simply and directly proportional to the current, or must we admit that the proportion is not a simple but a complex one? Professor Wertheim Salomonson has quite recently* raised this point, and has put it very simply by advancing the view that the production of X-rays is proportional to the watts expended in the tube, and not to the current traversing it. This would mean that in order to obtain a measure of X-ray production we should take into account not only the current, but also the electromotive forces necessary to produce that current. The Professor, though maintaining the view that X-ray production is proportional to the watts rather than to the current, does not bring forward in his paper any direct evidence to support it, although he states that some experiments made by himself with photographic plates appeared to show that there was a greater production of X-rays in proportion to current when high electro-motive forces were employed. Other observers have not noticed this relationship. D'Arsonval, on the contrary, has shown a series of X-ray photographs in which the effect was proportional to the current through the tube, and bore no reference to the watts expended.

In a communication made at the meeting of the British Electrotherapeutic Society in Leicester in July last a number of X-ray photographs were shown by the present writer in which the photographic effect appeared to be closely proportional to the currents through the tube, and these photographs show no direct relationship with the number of watts expended. Further evidence must be brought forward before the views of Professor Salomonson can be accepted. It is necessary to bear in mind that part of the energy expended in the X-ray tube appears in the form of heat. This fraction may be a large one, and in any case it must be deducted before we can venture to calculate the output of X-rays from measurements of the

* *Journal of the Roentgen Society*, December, 1905.

energy applied to the tube. It is quite likely that the waste of energy in the form of heat may account for a large proportion of the total energy expended, and it is certain that no simple wattmeter measurement of the energy expended in the X-ray tube can be of any direct use.

Dr. H. G. Adamson,* in a recent note, has given some figures of the times of exposure necessary for producing the standard change of tint in Sabouraud's pastilles with tubes of different degrees of penetration, and with measured currents, and these figures seem to indicate the possibility of a greater effect from the same current when the voltage is higher.

Dr. Milton Franklin has proposed to measure the amount of

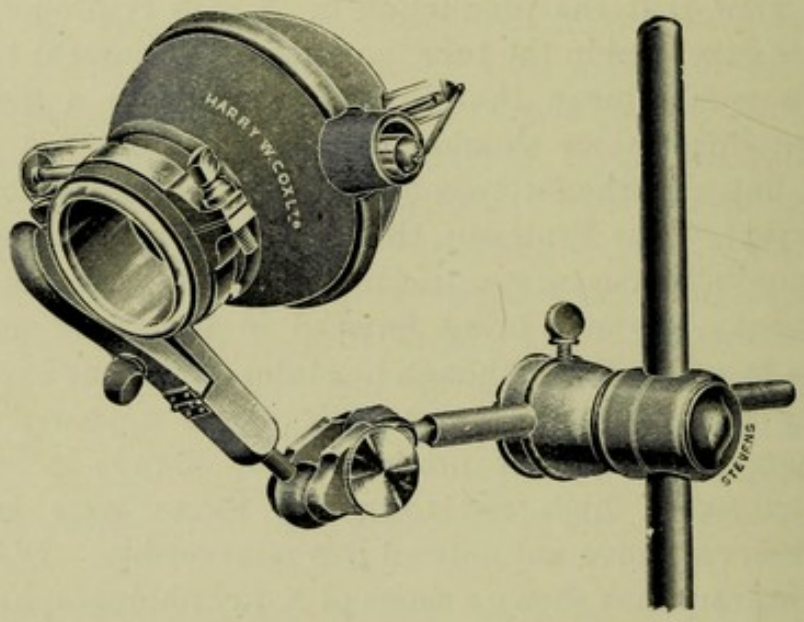


FIG. 159.—TUBE-HOLDER, WITH UNIVERSAL JOINT AND TUBE-SHIELD.

radiation from a tube by observing the rate at which a charge leaks away from an electroscope submitted to the rays, and it is possible that a practical instrument based upon this method may be forthcoming in course of time.

155. **Tube Stands.**—The clamps by which X-ray tubes are held are of many patterns. They should be made of wood, and should be sufficiently massive and well balanced to prevent vibration of the tube from being set up by slight disturbances in its neighbourhood. Fig. 158 shows a good form of stand and tube-holder made by Mr. Schall. It has the advantage of being constructed of wood, of being stoutly built, and of being sufficiently tall for all purposes. The upper crossbar serves to

* *British Medical Journal*, February 10, 1906.

hold up the wires well away from the patient, who is thus less likely to come accidentally into contact with them. The stand is 5 feet high. The wires from the coil may be led directly to the ends of the upper crossbar, but it is better that they should first be taken to a galvanometer and to a valve-tube, as shown in the drawing. Separate wires lead from the ends of the cross-arm to the terminals of the tube.

Messrs. Gaiffe also make a very good tube-holder, which is adapted to take a tube-shield, and enables the tube to be centred in the shield with ease. It is also fitted with a carrier for Sabouraud's pastilles.

The ball-and-socket joint, as shown in Fig. 159, is a valuable adjunct to an X-ray tube-holder, because it greatly simplifies the putting in position of the X-ray tubes.

The best position of the tube in relation to the plate is that in which the long axis of the tube is parallel to the plane of the limb to be photographed. Nothing is gained by tilting the tube so as to bring the anti-kathode surface parallel to the limb or the photographic plate. On the other hand, nothing is lost by such an inclination of the tube.

The cone of rays emitted by a tube in action is one of such a large angle that it is usually easy to include the whole area submitted to the rays in its more central parts. Definition and illumination are naturally better in the centre of the cone than at its extreme edges.

156. **Couch for X-ray Work.**—Many forms of special couch have been devised for X-ray work. In most of them the tube is fixed beneath, and the examination is conducted with the patient in the recumbent position, while the screen or photographic plate is above.

For most screen examinations, except, perhaps, in simple inspections of the upper limb, it is a convenience to have the patient in the horizontal position. The tube is fixed on a carriage, moving upon guides beneath the couch, so as to traverse in all directions without interruption of the connecting wires, and the part of the couch upon which the patient lies is made of cotton or other material transparent to X-rays. With a couch of this kind any part of the body can be inspected at will, and neither the patient nor the operator need adopt the uncomfortable attitudes which are sometimes required for the examination of a patient in a standing or sitting posture. Fig. 160 shows an

example of this kind of couch. A pillow may be placed beneath the patient's head to make him more comfortable. The carrier for the screen or the photographic plate can be displaced as desired, and its movements are followed by the tube beneath the couch. This, in its box, is seen below, and a screw is provided for giving to the tube a measured amount of displacement when the couch is being used for localization and stereoscopic work. The tube-carriage moves along rails, so that the tubes can be brought vertically beneath any desired part of the subject, and

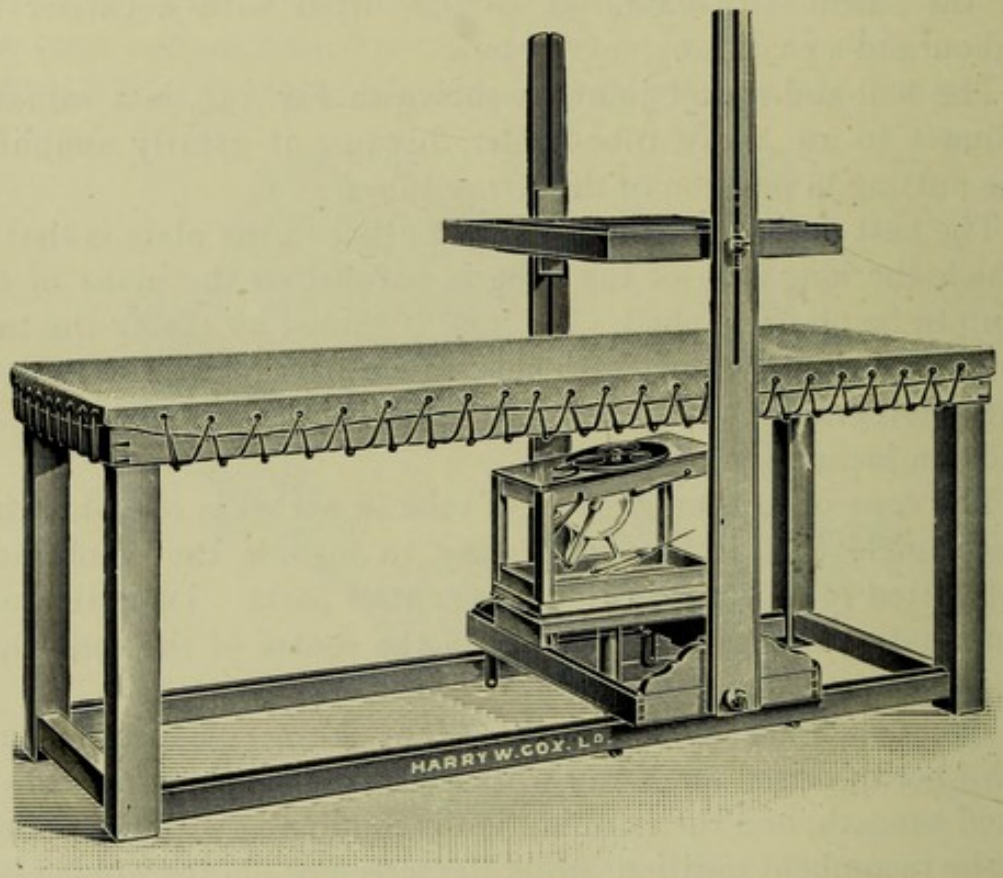


FIG. 160.—X-RAY COUCH.

the plate-carrier and the tube-carrier both move together, so that they always preserve the same relative position.

Although many workers prefer to have the tube beneath the patient and the plate above, not only for screen examinations, but also when taking photographs, others still adhere to the original method of placing the tube above and the plate beneath. The couch shown in Fig. 160 should be fitted with an upper horizontal bar on which to fix a tube-holder, the plate-carrier being removed when the tube is used above the couch. With this method there is less probability of movement on the part of the patient.

An extremely ingenious couch has been designed by Macintyre

for use in this way, as well as for use with the tube beneath. It consists of three portions, all of the same size and height. Two portions are simple square tables with cushions, and they can be folded up to economize space when they are not in use. The third table is fitted with a pig-skin top, at the same level as the cushions, and a slide is provided which allows of the introduction of a plate underneath the pig-skin, or of the substitution of one plate by another without disturbing the patient. Beneath this slide a fluorescent screen is fixed, and below it there is a mirror, inclined at an angle so as to allow the operator to view the screen comfortably during the actual exposure. The tube-support is provided with all the necessary adjustments for taking stereoscopic pictures with displacements of the tube as will be described, and for localization by Mackenzie-Davidson's method. To suit the region of the patient under examination, the section of the couch which has the skin-window can be placed either in the middle or at one end of the group of three tables which forms the couch. For use with the tube beneath the couch the mirror and fluorescent screen are removed, and a tube-stand is placed below, the one above being taken away.

Mr. E. W. H. Shenton has devised a special couch for radiograph work, which is so arranged that, by a turn of a screw-handle, the lamp-box can be moved instantly and noiselessly in any of three directions—that is to say, vertically, horizontally, or laterally—and thus brought to bear without any trouble upon any part of the patient's body which it may be desired to observe with the screen, or to radiograph. There is a foot-pedal arrangement by which the light can be switched on or off at once without delay or stooping. The top of the couch is quite free, and, being provided with drop-handles, can be used as a stretcher if desired for the removal of a patient without disturbance. To facilitate cleansing it is fitted with a loose pegamoid cover.

Mr. A. D. Reid has designed a couch (Fig. 161) of convenient size and shape for general radiographic work, and fitted with a special arrangement for turning the current on and off by means of the respiratory movements of the patient. The object of this is to ensure that the exposure shall be made at a certain stage of the respiratory cycle so as to reduce the displacements occurring during breathing to small limits. He has found this of special value in the photography of the kidney. The clock counts only the times of actual passage of the rays, and strikes a

bell at the expiry of the period of time for which it has been set beforehand.

With the aid of this apparatus compression is entirely dispensed with. Briefly, the operation is as follows : The patient is laid upon the X-ray couch face downwards, an air-cushion being placed underneath the part to be radiographed. The X-ray plate is placed on the patient's back, and on the top of the plate

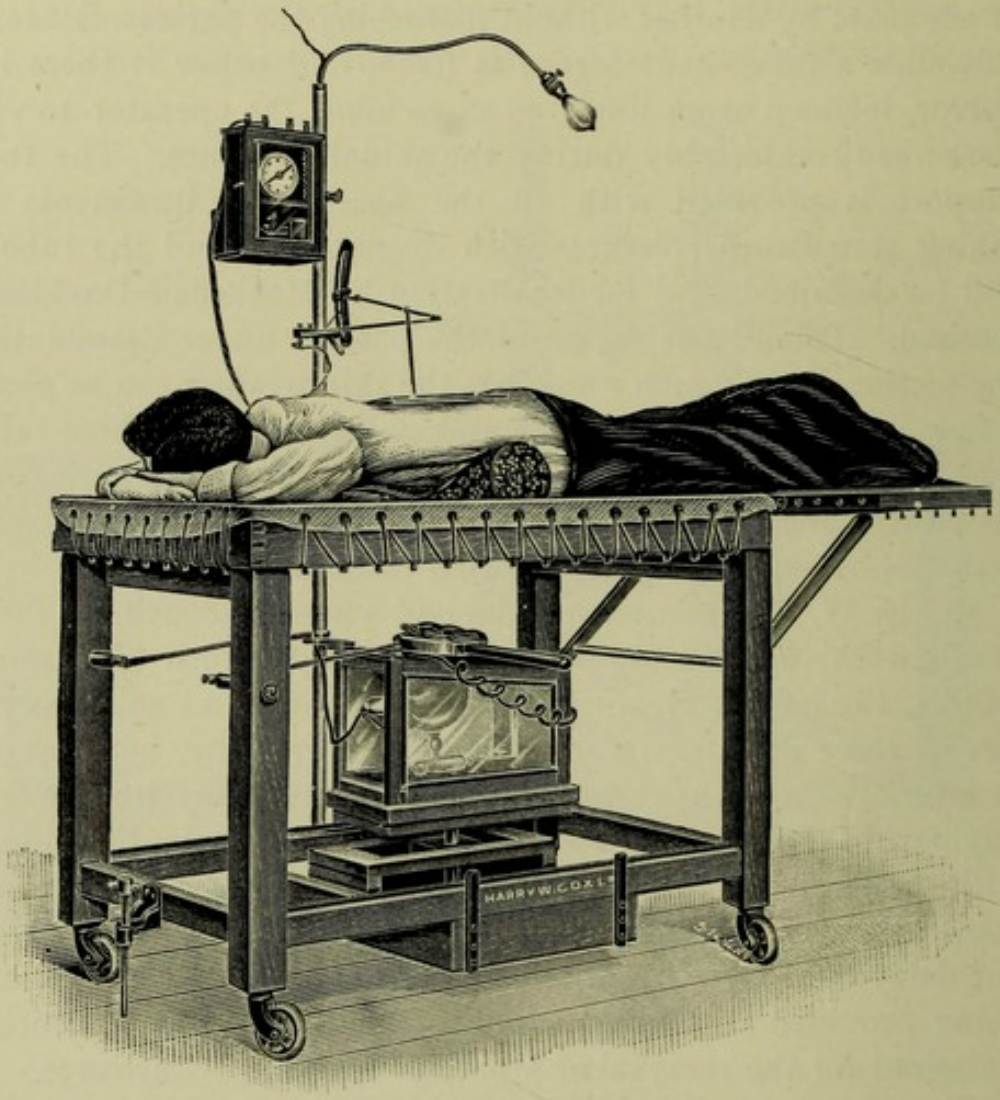


Fig. 161.—Couch with Clock for Time-exposures.

the upright arm shown in the illustration (Fig. 161) is fixed. This arm rises and falls as the patient breathes, and at full inspiration causes the lever to make contact. Simultaneously with the duration of this contact the clock shown in the illustration moves on, and records the time of the exposure.

It can therefore be seen that the kidney, or whatever part is being radiographed, is always in the same position when the tube is in action.

The apparatus is also useful for taking radiographs of the heart, lungs, etc.

157. **The Fluorescent Screen.**—This is a contrivance for producing with the X-rays an illumination which can be perceived by the eye, and it affords a means of judging of the quality and quantity of the radiations of an X-ray tube, and renders possible the direct inspection of bodies by means of X-rays without the intervention of a photographic process.

The principle upon which the fluorescent screen is based is the property possessed by X-rays of causing phosphorescence or fluorescence in certain chemical compounds. For the manufacture of screens a fluorescent body—that is to say, one which is luminous only during the continuance of the excitation—is better than a phosphorescent body in which the luminous effect is more or less persistent ; and on this account the phosphorescent compounds calcium tungstate and zinc sulphide are not now used for screens, as with these bodies there is a persistence of the images or after-effect, which tends to blur the sharpness of what is seen upon the screen. Barium platinocyanide, the compound originally preferred by Professor Röntgen, is still the best compound known for practical use, and commercial fluorescent screens are coated with this material.

Potassium platinocyanide is also used, but does not keep so well, as the salt tends to effloresce, and then is no longer fluorescent. Good screens can also be made with uranium oxyfluoride, but this preparation has not come into general use.

Fluorescent screens are made by spreading an even layer of finely-crystalline barium platinocyanide upon a flat support, thin cardboard or vellum being usually employed. Great care is necessary in their preparation. The crystals must be of uniform size, and should form a layer of uniform thickness. About four grains are sufficient to cover a square inch. A favourite method of manufacture is to mix the barium salt into an emulsion with collodion, amyl acetate and acetone, and to spread it in a liquid form upon the support, which is then left in a horizontal position until the mixture is dry.

Fluorescent screens are mounted in light wooden frames, and are backed with black paper. When new the surface should have a lively greenish-yellow colour. A sheet of glass should be used to protect the surface from dust or finger-marks.

The fluorescent light emitted by the screen is also of a greenish-

yellow hue, and is not of a high degree of brilliancy, and for work with the screen it is necessary to have the room perfectly dark. Some workers even enclose the X-ray tube in a black silk covering to exclude the light given out by its walls, and others have recommended the use of tubes coated with a dark-coloured varnish with the same object. As the retina becomes very much more sensitive after a few minutes' rest in darkness (according to Béclère, a period of rest in a dark room of twenty minutes' duration increases the sensibility of the retina 100 times), a short period may be usefully spent in the dark room as a preparation before commencing operations. When difficult cases are to be examined this is a very great help, particularly in the daytime, though after nightfall it is less necessary, as the retina is then already partially prepared. The eyes of the young are much better able to discern faint appearances upon the fluorescent screen than are those of their elders.

These screens should be exposed to light occasionally. The prolonged action of X rays gradually causes a change in colour through which the screens lose the greenish tinge which they have when new, and acquire an orange-brown tint through loss of water from the crystals of the salt, and in this condition their fluorescent powers are considerably lessened. This change is partly obviated by exposure to diffused daylight, but bright sunshine by heating the screen does harm.

In examining an object with the fluorescent screen, the latter must be kept in close apposition with the object. If this is not attended to the images will be less distinct, and will appear too large, because the pencil of rays emitted by the tube is of a divergent character. The nearer the object and screen are to the tube the greater will be the exaggeration of the size of the image, while very serious distortions are produced if the object examined be not in a plane parallel to that of the screen. These effects can be very well studied by the use of the screen, and much can be learned in this way which will prove of great value when the taking of X-ray photographs is being practised. The posing of the limb, so that it is in proper relationship to the tube and to the plate, plays a very important part in successful X-ray photography.

The value of the fluorescent screen in practical work lies in the ease of its application. By its means any region of the body can be examined from all sides, and that in a comparatively short time. Its indications will suffice for a large proportion of medical

and surgical cases, particularly for those in which coarse injuries of bones or of joints are being investigated, and for most foreign bodies; also for examinations of the thorax in experienced hands. On the other hand, the screen image is not able to reveal so much of the fine detail as can be seen in a photograph, and for difficult work the latter will consequently be preferred. The action of the X-rays upon a photographic plate is cumulative, and thus it can collect during exposure, and can reveal, on development, a number of points which might escape notice in a screen examination. Moreover, the photograph gives a permanent record, and one which can be measured and can be studied by several independent observers.

The cryptoscope or fluoroscope is an arrangement of the fluorescent screen designed to permit of examinations being made in a room which is not darkened. It consists of a camera or dark box, at one end of which is a fluorescent screen, while the opposite end is provided with apertures for the eyes of the observer. The screen is thus viewed in darkness even in a lighted room.

The instrument is not of great practical value for diagnostic purposes, but is often useful for making a preliminary examination in order to verify the position of the patient and the working of the tube before making an exposure.

A common size for the fluorescent screen is one of ten inches by eight inches. Larger or smaller ones may also be used. But the small screen is often to be preferred to a larger one, because with a screen much larger than the part under scrutiny the eye may be troubled by the fluorescence of the outlying portions.

The regeneration of discoloured platinocyanide screens would be easy were it not for the waterproof celluloid varnish in which the crystals are enveloped, but this prevents the access of moisture which is necessary to restore their original colour.

The operator must refrain from examining his own hand too frequently, as by doing so he is very likely to prepare the way for chronic dermatitis, a condition which is of extreme gravity. In screen-work there is a tendency to approach the object nearer and nearer to the tube for the sake of the extra illumination which is gained from proximity to the source of X-rays, and this is favourable to the production of dermatitis. Moreover, an interested observer may easily spend many minutes in examining the striking effects shown by the screen, and may forget that there

is a danger of setting up acute dermatitis if any one part is kept close to the tube for any length of time.

It would be of great advantage for X-ray work if some compound of the nature of a dye could be discovered which would fluoresce with X-rays. Fabrics dyed with such a material and woven into tightly-fitting garments would do away to a great extent with the distortions which are inevitable when shadows are projected upon a plane surface, such as a flat screen.

158. **Cabinets and Trollys.**—The apparatus necessary for X-ray work may be assembled together in a cabinet or cupboard with

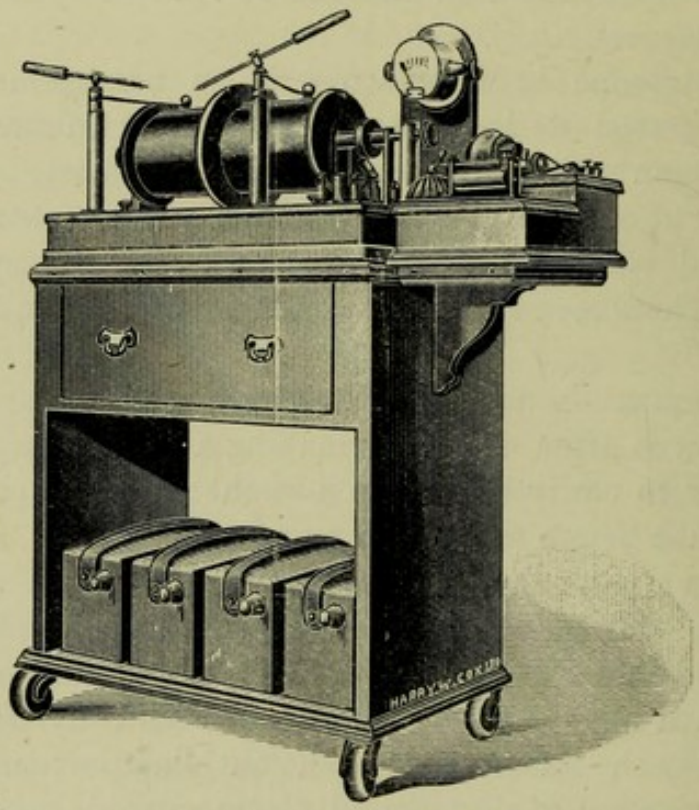


FIG. 162.—X-RAY TROLLY FOR WARD USE.

great advantage, particularly when the room in which the X-ray work is done is also required for other purposes. Most makers of X-ray apparatus can supply cabinets of the kind required, and an inspection of their catalogues is recommended to any intending purchaser.

A less ambitious apparatus consists of a strong table or trolly on castors, with a lower shelf for the receptions of the accumulators or the interrupters, and an upper one for the coil. Three shelves may be provided with advantage in some cases, and when most of the work will be done with the tube under the couch, the coil can be very conveniently placed on one of the lower levels.

It is always an advantage to be able to bring the coil close to the tube, as this obviates the need for long lengths of secondary wire. These are awkward in a dark room, both because patients or visitors may come into accidental contact with them, and because they are apt to come into sparking distance of each other when the tube and tube-stand are moved about for purposes of adjustment to the requirements of a case.

If a fixed position is preferred for the coil, a convenient way of arranging the secondary wires is by means of overhead suspension, bringing them down to the ends of a cross-arm fixed to the upper part of the tube-stand (see Fig. 158). The wires from the ends of the cross-arms to the tube itself are then independent of the rest of the circuit, and if wound in spirals they will have sufficient elasticity to allow of all likely displacements of the tube without any deformation, and will preserve their symmetry for a considerable time.

It may be more convenient to have the coil on a movable trolly, like that shown in Fig. 162, and to connect to the mains by means of a cord with counter-weight suspended from the ceiling, just as is done in the case of electric lighting pendants. The cord may then terminate in a lamp-socket, which can be slipped on to a plug fixed on the trolly or on the base-board of the coil. If a shunt-circuit resistance is used to lower the pressure of supply, this can occupy an adjoining place on one of the walls. The interrupter may be given a place either on the trolly itself or upon a shelf in a convenient corner near the wall-plug from which current is taken.

For military purposes* Messrs. Gaiffe have constructed a 10-horse-power automobile waggon with a complete X-ray outfit. It contains an alternating dynamo, driven by the engine of the automobile, and a high-potential transformer apparatus. The waggon is closed, and its interior can be darkened by means of shutters for radioscopic and photographic purposes.

159. **X-ray Photographs.**—In medical work X-ray photographs are taken by means of photographic plates enclosed in light-tight envelopes of paper, or in light-tight plate-holders. The plate is usually enclosed in a yellow envelope, which again is enclosed in a black envelope. By this means the action of ordinary light upon the plate is prevented, but the passage of X-rays to the plate is not interfered with.

* *Journal of the Royal Army Medical Corps*, November, 1905 (with figure).

In putting the plate into the envelopes before exposure a little care is needed, in order that the film or sensitive side may face in the right direction. The plan is to put the plate into the yellow envelope with its film side away from the flap or opening, and then to put this into the black envelope, with the plain sides in apposition. The side with the flap or opening of the envelope is then the side of the glass or non-sensitive side; the other is the side of the film which must face the X-rays.

Envelopes of the proper kind can be obtained from the makers of photographic materials. Plate-holders of polished wood with thin ebonite fronts are also used. The plate enclosed in this way is laid upon a table or other support, and the limb is placed upon it. The tube is then adjusted at a distance of a foot or eighteen inches above the limb, and the coil is set in action. The limb or part must be kept quite still during the exposure, which may last from a few seconds up to a minute or more, according to the efficiency of the apparatus and the density and thickness of the part to be photographed. Care must also be taken to avoid vibration or movement of the tube. As soon as the exposure is concluded, the coil is turned off, and the plate, still enclosed in its envelopes, is removed to a dark room, where its development is carried out in the ordinary way, as in simple photography.

The average exposures with a 12-inch coil strongly driven with mercury-jet interrupter and 100 volts from mains on coil are as follows (distance, 18 inches):

Hand and Wrist	5 to 10 seconds.
Forearm, Elbow, and Arm	10 to 20 ,,
Shoulder	20 to 30 ,,
Thorax	20 to 30 ,,
Foot and Ankle	15 to 20 ,,
Knee	about 25 ,,
Leg	about 20 ,,
Thigh	20 to 30 ,,
Hip	30 to 35 ,,
Pelvis	30 to 45 ,,
Abdomen	35 to 40 ,,
Head	30 to 60 ,,

These exposures are those found by experiment to be correct for Imperial flash-light plates. If Lumière X-ray plates are used the exposures may be shortened. For example, a good negative

of the abdomen may be obtained in thirty seconds with the latter make of plate.*

With smaller coils longer exposures will be necessary. But it must not be thought that a long exposure with a small coil will give equivalent results to those obtained from a short exposure with a large coil. The larger the coil, the quicker may be the exposure, but in addition the sharper would be the picture.

Various kinds of photographic plates have been specially recommended from time to time, but there does not seem to be any conspicuous difference between one kind and another. It is better to choose one kind of plate and adhere to it, because in this way the peculiarities of the plate during development are the more quickly learned. Lumière X-ray plates are good.

As with choice of plate, so with choice of developers; it is best to make use of those with which one is best acquainted. A very simple and convenient developer is rodinal. It has the advantages of easy preparation and of rapid action, and it does not stain the fingers. "Metol-quinol" is also a good developer, and gives a fine brown tone to the negatives. As with X-ray work the exposures are seldom very far removed from what may be called the minimum normal exposure, a simple developer of maximum strength can usually be employed without the risk of spoiling the plate in the process of developing, and whenever the exposure and the development are both carried out by the same person it is found that a time is soon reached when one may very closely assimilate time of exposure and strength of developer so as to give the best results. The question of skilful development belongs rather to photography than to medical electricity, and in many cases the plates are sent for development to professional photographers.

An over-exposed plate may be known by a fulness of detail in the whole plate, which is thin if development is cut short, but shows a general blackness of the whole subject if development is fully carried out, while an under-exposed plate long developed shows very great contrasts, with absence of detail in the parts least blackened. In general, one should not curtail the times of exposure, as it is desirable to get all the detail which is possible.

160. **Practical Note.**—The proper management of Röntgen-ray work involves attention to a number of details, and demands

* For this table the writer is indebted to Dr. G. Harrison Orton, Clinical Assistant in the Electrical Department of St. Bartholomew's Hospital.

much careful study and practice ; without experience the operator may produce nothing but poor results, even with the best and most costly coil.

In connecting the coil to the source of current, the coil attachments must be made first, and the attachments to the battery terminals or mains afterwards. Before connecting to the latter be sure that the switch on the coil is not closed.

The form of commutator usually fitted to coils is that of Ruhmkorff (Fig. 26). It fulfils a dual purpose. When the switch handle is standing upright it interrupts the primary circuit, and prevents the current from passing from the battery to the coil ; when turned down to the right it allows the current to pass in one direction through the primary circuit ; and when turned down to the left it reverses the current and allows it to pass in the opposite direction. The commutator should move stiffly, otherwise an accidental movement might set the coil in operation at an awkward moment, communicating a shock to the operator or to any other person who might be in contact with some part of the circuit. When working alone it is useful to insert a visiting-card between the contacts of the commutator when it is turned off, as this obviates the risk of turning on the current accidentally—by the coat-sleeve, for instance.

The X-ray tube must be securely fixed in its holder, and connected to the coil by lengths of fine insulated copper wire.

These should not be so near to each other at any part of their course that sparks can pass between them instead of through the tube. In their course to the tube they should not run obliquely, or one of them may lie too close to the bulb of the tube, and a spark may pass at that point and puncture the glass.

To ascertain the direction of the current the appearance of the tube in action is taken as a guide. If, when the switch is turned on, the tube shows an even hemisphere of green fluorescence on the side facing the front of the anti-kathode, then the current is in the right direction, but if the green light is patchy and irregular the direction is probably wrong. By the use of the fluorescent screen all doubt may be set at rest, for when brought up to a tube through which the current is passing in the right direction it will be illuminated brightly, and the hand placed behind the screen will show the shadow of the bones distinctly. If the direction of the current is wrong scarcely any Röntgen rays are produced,

so that only a feeble fluorescence of the screen can be perceived.

When the coil and the tube are working satisfactorily the room should be darkened, and the fluorescent screen should be brought into use. The hand should be held flat against the back of the screen, and both should be approached to the front or fluorescent hemisphere of the tube. The bones will then be seen, and a few experiments should be made to note the peculiar effects of distortion which become evident if the wrist and fingers are twisted into irregular and oblique positions away from actual contact with the back of the screen. By using different tubes the variations in the density of the shadows of the bones can be noted, and this variation should be compared with the resistance of the tube, as determined by measurements of the alternative spark-length at the discharging terminals of the coil.

In photography the distance of the tube from the object is important. The length of the exposure will vary according to this distance, the magnitude of the current through the tube, and the thickness and opacity of the object. It need scarcely be urged upon the beginner that he should practise with his apparatus in order to learn the methods by which the best results are to be obtained before taking photographs of patients. He will find in his own person, or in that of an interested friend, a convenient subject for experiment. When he has succeeded in taking every part of his own body, he will be prepared for the ordinary difficulties of Röntgen ray photography.

The distance of the tube from the plate, and from the parts to be radiographed, is an important question on account of "distortion." When special sharpness is wished for it is best to have the tube at a comparatively great distance, and to give a longer exposure. In this way distortion may be reduced to a minimum.

Where there are bones in two different planes the image of those nearest the tube may tend to obscure those near the plate. If a picture of the latter is wanted without the former it is a good plan to have the tube very close. For example, if a picture of the upper part of the spine be desired, the tube may be placed nearer the sternum than if a general view of the heart and lungs were wanted. The bones of the sternum nearest the tube will then be given indistinctly, and their tendency to obscure the image of the vertebræ will be less evident. Clearness of definition

also depends upon other conditions. All movement on the part of the apparatus should be guarded against.

Although the clothing is practically transparent to X-rays, yet it is desirable, when taking a Röntgen photograph through a thick part of the body, as the thigh or hip, the trunk or the pelvis, to remove superfluous clothes, as they offer some slight resistance to the rays, both by their material and by their dyes, but especially because buttons or hooks and eyes or pins in the clothing will leave their impressions on the plate, and may thus obscure the result.

It is in the photography of thick parts of the body that difficulties are met with. The chief of these is due to want of definition, but distortion of the images must also be reckoned with. One often finds, instead of a sharp image on the plate, that there is only a vague blackening, with little or no detail, a result which is due mainly to the phenomenon of diffusion and the action of secondary rays. The effect of diffusion is to blur the image, just as happens with ordinary light when an object is viewed through a turbid or foggy medium. Professor Röntgen showed that bodies in general behave towards the rays as turbid media do to light ; he also showed that secondary rays were produced by the rays when they impinged upon solid bodies, and that even the air traversed by X-rays becomes a subsidiary source of other irregular X-rays, which, though feeble, are sufficient to blacken a sensitive plate during a long exposure.

Again, the reverse currents of the coil pass through the X-ray tube and excite an irregular production of X-rays, which tend to blur the photographic image.

Various means can be adopted to counteract these bad effects. The valve-tube of Villard can be used to arrest the impulses which tend to traverse the tube in the wrong direction, and by placing a thin layer of aluminium in front of the plate one may stop the radiations of low penetration while permitting the others to pass through. The use of a plate of lead or of thick plate-glass as a backing to the plate is also said to sharpen the photographic image by absorbing the rays which have penetrated the plate before they can give rise to secondary radiations behind it.

The use of diaphragms in the form of short cylinders of lead or of some other opaque body between the tube and the subject have also been recommended, with the object of cutting off all

but the central portion of the cone of rays emitted by the tube.

These diaphragms, recommended particularly by Dr. Thurstan Holland, are of distinct service in photographing difficult subjects, as, for instance, the hip-joint or the kidney.

In general, the details of an X-ray photograph can be seen better in the negative than in a print, and the print has the disadvantage of being reversed, whereas the negative is not so.

For the examination or the exhibition of "negatives" a lantern illuminated by artificial light is most generally convenient. The simplest form resembles an ordinary dark-room lamp in which the negative is inserted in the place of the pane of ruby glass. The effect is improved if a sheet of plain ground glass is placed behind the negative, and if the negatives are very thin a sheet of opal glass is even better. Such a lantern made of japanned tin, with a semi-cylindrical back, and painted white inside, can be made very cheaply by a tinsmith to take the size of negative most commonly made use of. An electric lamp affords the best means of illuminating it.

Elaborate lanterns made in cabinet work for the illumination of X-ray negatives are figured by the instrument-makers, but as they cost from three to five pounds, they are rarely seen in practical use.

161. **Protecting Devices.**—The risk of producing injury by exposures to X-rays has led to the introduction of various protecting devices. Two separate conditions of danger must be guarded against: one is the risk of acute dermatitis in the patient, and the other is the risk of chronic dermatitis and other troubles in the operator.

Formerly when X-rays were used for therapeutic purposes it was customary to cover the healthy parts around the affected region by means of a sheet of thin lead in which a hole had been cut of a size and shape to suit the part under treatment. Then if dermatitis were set up by the treatment its extent was limited by the size of the opening in the leaden screen. Subsequently the use of special therapeutic tubes was recommended, and as lead glass is comparatively opaque to X-rays, the tubes were constructed of this material, and were provided with a "window" of thin soda-glass at the end of a special prolongation or side-tube. Thus the emission of X-rays from the tube was limited to a small area corresponding to the area of the soda-glass window,

Other special forms of tube which may be mentioned here are those designed for use within the cavities of the body, and particularly within the mouth for dental purposes. In these tubes the anti-kathode is at the slender end of a cylindrical or pear-shaped prolongation, and its leading-in wire is protected by a thick glass sleeve, or it is carried inside the tube for some distance. For safety the anti-kathode wire is earthed, as must also be the anode of the generator. These tubes are of small size, and can best be operated from a 2-inch coil or from a small static machine. For dental work various patterns have been devised, and the reader should refer to the papers of Mr. C. A. Clark * for further details of this interesting branch of X-ray work.

In order to protect both operator and patient, Mackenzie Davidson and F. H. Williams bury the tube in boxes of white-lead powder, leaving an opening on the side opposite the anti-kathode through which a cone of X-rays can emerge.

At the present time tubes are generally enclosed either wholly or partly in a cup-shaped shield made of thick glass, or of some composition which is opaque to X-rays, and many varieties of tube-shield of this type can now be bought. A tube-shield should not be so heavy as to be unsuitable for use with the tube-holders in ordinary use. It is almost impossible to find a material which is absolutely opaque to X-rays. Even metal is not absolutely opaque, for X-ray photographs have been taken of pistol barrels showing the bullet within the bore, and it is better to be content with a moderate degree of partial opacity if in that way a shield can be obtained which is light enough to be carried comfortably by an ordinary tube-holder.

Fig. 159 shows a very good form of tube-shield made of a dense compound of indiarubber. The illustration explains its shape and the mode of attachment to the tube, and a series of glass nozzles and diaphragms with variously-sized openings can be adapted to it, when it is desired to limit the action of the X-rays to a very small area.

As the parts which suffer most from the chronic dermatitis of operators are the backs of the hands, gloves can be used to serve as a protection. Shield gauntlets of heavy indiarubber are now made, and something of the kind should always be worn to

* "A New Dental X-Ray Tube": *Archives of Roentgen Ray*, June, 1903; *Medical Electrology and Radiology*, 1903, p. 201; *Transactions of the Odontological Society of Great Britain*, April, 1903, p. 171.

guard against the insidious development of that most serious trouble, chronic X-ray dermatitis.

Dr. J. M. H. Macleod has recently described* a very convenient form of tube-holder with shield. It consists of an upright stand carrying a large square triple frame of wood, within which a cup-shaped shield of thick glass is held in such a manner as to be freely movable in any direction. The cup-shaped glass

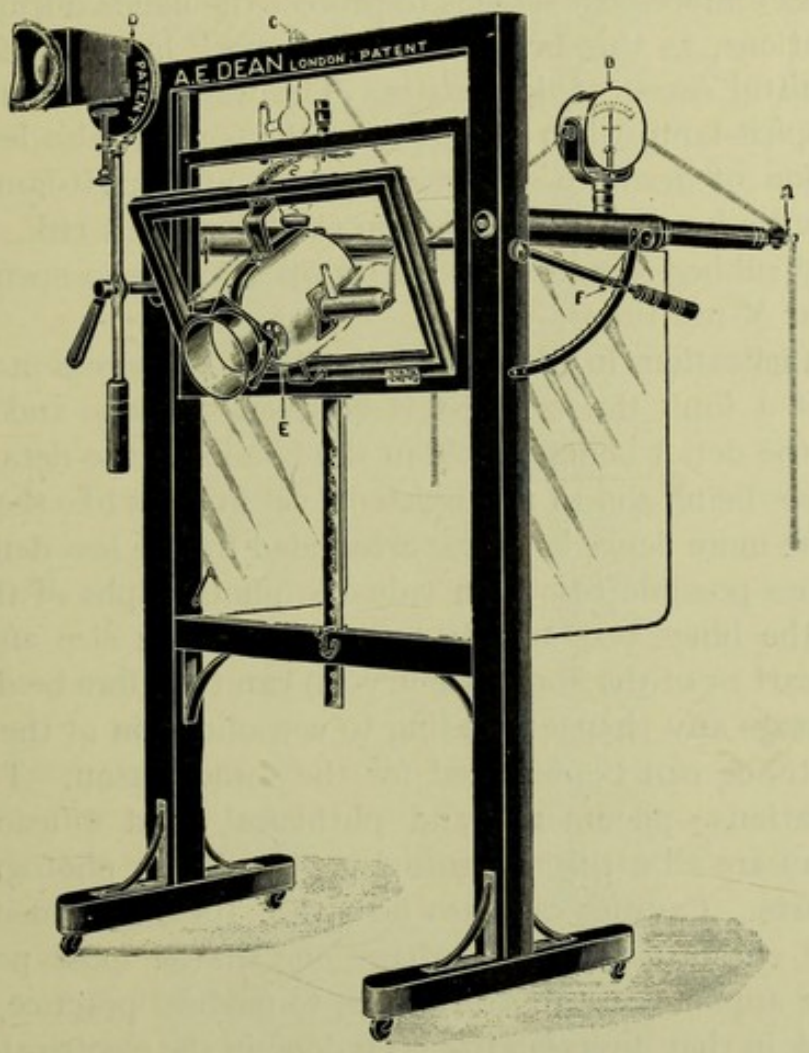


FIG. 163.—DR. MACLEOD'S STAND AND SHIELD FOR X-RAY TREATMENT.

shield partially encloses the X-ray tube, and has a central opening into which short cylinders of glass can be fitted to suit the area of the part to be exposed to the rays. The stand also carries a milliampèremeter, a Villard valve tube, a spark-gap measurer, and a small fluoroscope for observing the quality of the radiations given out at any moment by the tube, and forms a very complete and useful outfit for purposes of X-ray

* *British Medical Journal*, September 16, 1905.

treatment. In connection with the apparatus there is a magnetic time release attached to the interrupter of the coil, which cuts off the current when any pre-arranged number of interruptions and impulses have been completed. The apparatus is made by Mr. Dean (Fig. 163).

Other protective devices for the operator which may be mentioned consist in the provision of metallic shields or guards at the sides of fluorescent screens to protect the hands during screen examinations, as this branch of X-ray work has been found to be a fruitful cause of dermatitis. The warming of hard tubes with a spirit-lamp when in action on the coil has also led to the production of dermatitis in many cases, and spirit-lamps with long ebonite handles are now made to obviate this risk. Aprons of heavy rubber should be worn by operators who spend much time near X-ray tubes.

162. **Applications in Diseases of the Chest.**—Whereas in a photograph of a limb the contrast is between the bone and the soft tissues, the detail being visible in the bone and the detail in the soft tissues being almost non-existent, yet in cases like the thorax, where the more dense heart is surrounded by the less dense lung, it becomes possible to obtain valuable photographs of the heart and of the lungs respectively. Changes in the size and shape of the heart or of the aorta (aneurysm) can therefore be detected. In the lungs any changes tending to consolidation of the natural spongy tissue can be detected for the same reason. Tumours, consolidations—pneumonic and phthisical—and effusions into the pleura are all easily recognised in good X-ray photographs of those parts. Cavities can also be seen. Its employment in the study of chest diseases is perhaps one of the most promising of all the applications of X-ray work to medical practice. Valu able work in that direction has been done in the electrical department of St. Bartholomew's Hospital by Dr. Hugh Walsham.* He was the pioneer of this section of X-ray work, and his results have been confirmed by later writers.† This field of diagnosis is likely to progress considerably when it has been studied

* "Present-Day Skiagraphy," *Clinical Journal*, 1901, vol. xviii. (figures). "On the Diagnosis of Thoracic and Cardiac Aneurysms by the Röntgen Rays," *Edinburgh Medical Journal*, i., 1901 (figures).

† J. T. Halls Dally: "On the Use of the Röntgen Rays in the Diagnosis of Pulmonary Disease," *Lancet*, June 27, 1903. A. Stanley Green: "The Value of the Röntgen Rays in the Diagnosis of Pulmonary Tuberculosis," *Archives of the Röntgen Ray*, viii., 144.

further. In the photographs of the chest, as in those of the limbs, the combination of two pictures by means of the stereoscope is often of great value in enabling one to form an estimate of the actual position and depth from the surface of any tubercular consolidation or tubercular cavity, for a cavity can be revealed by X-rays just as well as a consolidation, although for the opposite

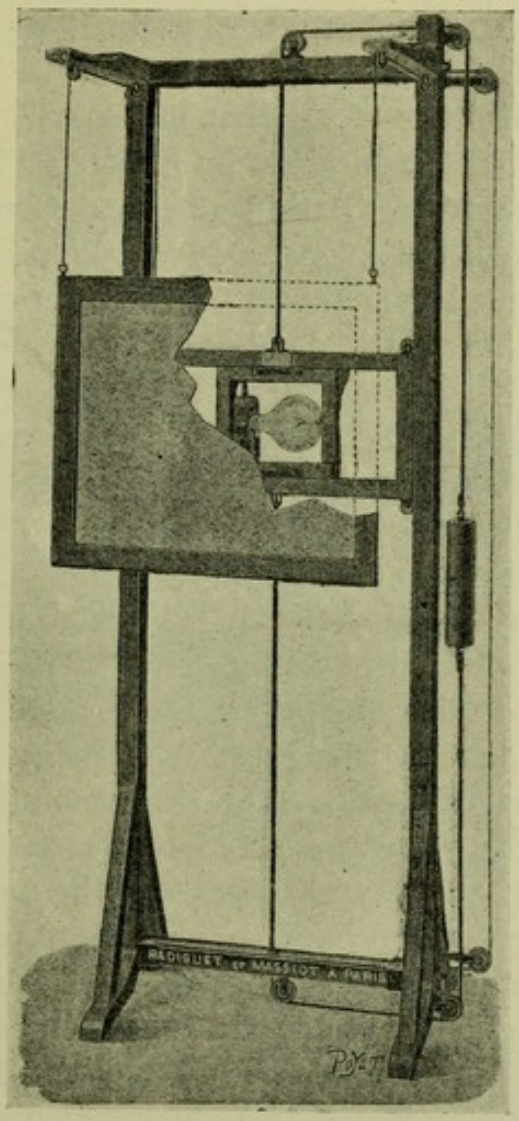


FIG. 164.—GUILLEMINOT'S STAND FOR TUBE AND FLUORESCENT SCREEN.

reason—namely, that whereas a consolidation is denser than the normal lung, a cavity is less dense.

It is unnecessary to dwell upon the value of the X-ray photographs as permanent records of past conditions in a slowly progressive disease like phthisis.

Fig. 164 shows a very useful arrangement due to H. Guilleminot for examining the chest with the fluorescent screen. It

consists of an upright stand, which carries the tube and the screen, and is provided with cords and pulleys, which permit of regular displacements of the tube in a horizontal or a vertical direction, and of the screen in a vertical direction only, the other movement not being necessary in the case of the screen. A metal cross is also provided to cast a shadow for ensuring that the tube is correctly placed for the direct rays to fall upon any part of the chest as desired, and this is a point upon which Dr. Guilleminot insists very strongly.

163. **The Localization of Foreign Bodies.**—A difficulty which soon shows itself in the localization of foreign bodies by means of X-ray photographs is the difficulty of determining the plane in the limb in which the foreign body is placed. Various plans for localization have been devised. In this country the stand and localizer of Mr. Mackenzie Davidson are in almost universal use.

The principle upon which Mr. Mackenzie Davidson's localizer depends is the measurement of the displacement of the image of the foreign body on the photographic plate which is produced by a measured displacement in the position of the tube. Two exposures are made upon the same plate with the limb perfectly still, a known displacement being given to the tube before the second exposure. This operation is easy with the forms of tube-stand provided for the purpose. Then, as the distance of the tube from the plate and the amount of the lateral displacement of the tube are both known, a diagram can be constructed taking in these two factors and the measured displacement of the image of the body on the photographic plate, and from this, by a calculation, the distance of the foreign body from the surface of the photographic plate can be deduced. In practice the calculations are very much simplified by the use of the localizing apparatus in which two threads represent the axis of the rays from the two positions of the tube. These start from the two points, and are brought down to the two images of the foreign body which are seen upon the photographic negative. The point where the two threads cross in the air above the negative is the point at which the foreign body is situated. That, indeed, is the only point at which it can be, in order to give the two images which it has shown. By means of simple measuring scales supplied with the apparatus, the height or the depth of the body from the surface with which the plate was in

contact is readily calculated by measuring the position of the point at which the threads cross in the air. Its distance to right or left from a given point in the photograph can also be measured quite easily.

A fine wire dipped in an aniline dye is tied round the packet containing the sensitive plate ; when the limb is placed in position and the photographs are taken, the image of the wire is

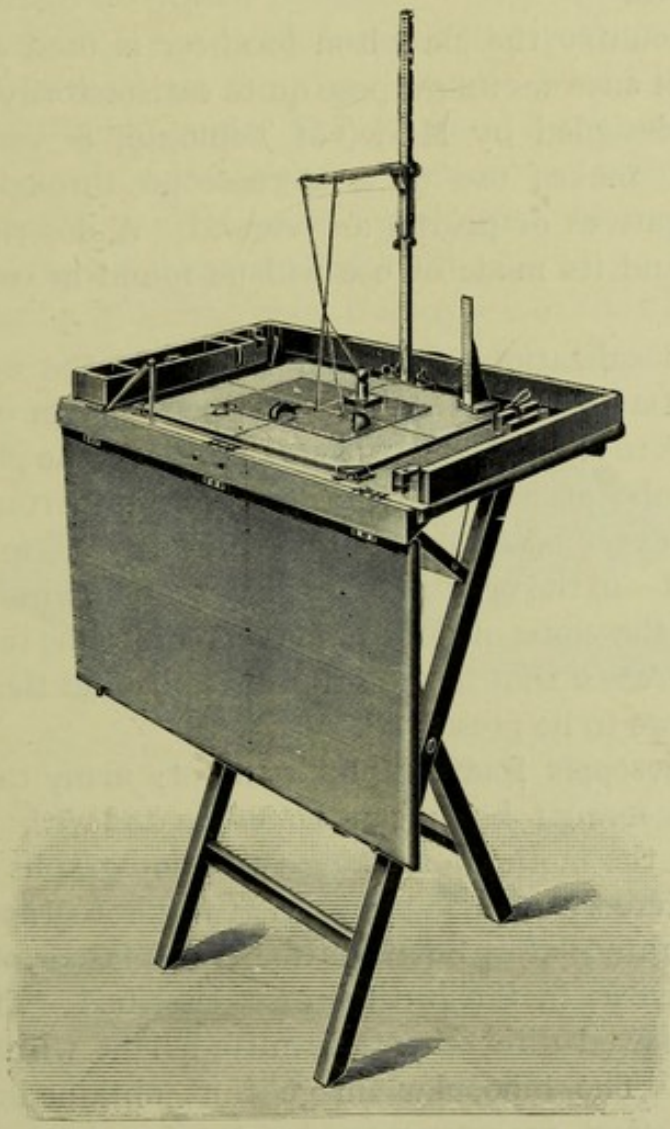


FIG. 165.—DAVIDSON LOCALISER.

recorded in the radiograph, and the dye leaves an imprint upon the patient's body. After development, the plate is placed beneath the localizer stand, and the two indicators, which are connected with the scale by means of silk threads, are set precisely to the corresponding spot in each of the images—the cord from the right-hand side going to the image on the left, and that from the left to the image on the right. The point of intersection of

the two cords gives the precise depth of the foreign body in the tissue. Fig. 165 shows the arrangement.

Its position laterally will be known by reference to the image of the cross wire, and as an imprint of this will be upon the patient's body, the surgeon can make an incision with absolute certainty of finding the substance sought for. The usual amount of displacement of the tube for the second plate is 6 centimetres.

In this country the Davidson localizer is used almost exclusively, and it answers its purpose quite satisfactorily. In France a method designed by Marie, of Toulouse, is very clever and simple. It makes use of a stereoscope through which the images (negatives or prints) are viewed. A description of this apparatus and its mode of use will be found in certain French works.*

For the localization of foreign bodies in the eye and orbit Mackenzie Davidson has designed a special form of head rest† which serves to support the patient's head and the plate, and also holds the tube at a fixed distance. The importance of determining the exact position of a foreign body—as, for instance, a pellet of shot—in the orbit may be very great, because the presence of a shot in the globe of the eye might require the removal of the eyeball, whereas a shot in the soft tissues behind the globe might permit the eye to be preserved.

164. **Stereoscopic Radiography.**—In very many cases the position of the foreign body can be estimated with considerable accuracy by the method of taking two photographs and viewing them in a stereoscope. For this the two photographs are taken on two separate plates, but the tube is displaced for the second exposure, just as in the process just described. The negatives should be viewed direct by transmitted light with a reflecting stereoscope. The binocular image thus obtained has a most remarkable effect in reconstructing to the observer's eye the entire part of the body in which the foreign body lies. It appears to stand out with all its roundness and thickness, and the foreign body can also be seen as it lies in the depth of the tissue in such a way as to give a very real picture of its actual position and depth from the surface.

* E. Castex: "Électricité Médicale," Paris, 1903. Bouchard: "Traité de Radiologie Médicale," Paris, 1904.

† *Transactions of the Ophthalmological Society*, 1898.

In order to obtain two photographs which shall be in correct register, some device in the nature of a changing box is used, so that the first plate may be removed after exposure, and a second plate substituted without any movement of the patient. This is secured by using a thin slide or box made with a calf skin or aluminium covering. The photographic plate, enclosed in a black paper cover in the usual way, is supported on a board, which is pushed into place beneath the cover of the box after this has been put in position beneath the patient, and a pair of wedges then raise up the plate and the board into a secure position immediately under the surface of the changing box. A horizontal bar above the couch carries the tube, and allows it to be displaced to either side, for a measured distance, before the second exposure is made (Fig. 166).

A wire may be stretched upon the surface of the calf skin, close over one edge of the plate and parallel to it. This leaves a white

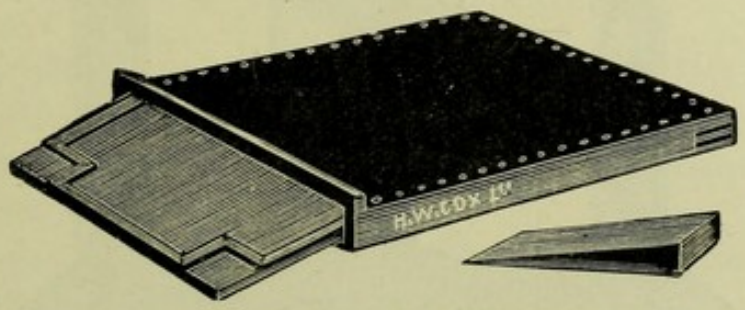


FIG. 166.—SIMPLE CHANGING BOX FOR STEREOSCOPIC PHOTOGRAPHY.

line across the end of each negative, and enables the photographs to be brought into correct register.

The Wheatstone form of reflecting stereoscope should be used.

"Two plane mirrors, about four inches square, are so fixed on a vertical support that their backs form an angle of 90 degrees with each other. When the observer puts his face close to the edge where the mirrors meet, so that this edge lies vertically between his eyes, it follows that his right eye can only see what is reflected in the right mirror, while his left eye can only see what is reflected in the left mirror. Now, if the two skiagraphs, taken as already described, are placed so that the right eye image is opposite the right mirror, and the left image opposite the left mirror, each eye will recognise its own picture, and they will combine, as usual, and give rise to a single image in perfect relief (Fig. 167).

"There are several devices for supporting the skiagraphs, and

also for simultaneously making them approach or recede from the mirrors. The simplest of all arrangements is to have the mirrors mounted on an upright block of wood, which can be placed upon a table, while the skiagraphs can be supported by any simple means in the proper position. The block supporting the mirrors is attached to a small base with bevelled edges, which slides in a broad groove, and enables the observer to slide the mirrors towards or away from his eyes. In this way the mirrors can be adjusted to the position which enables the observer to combine the pictures most comfortably. By means of a sliding base the distance of the skiagraphs from the mirrors can be altered at will.

"The Wheatstone stereoscope is peculiarly adapted for X-ray photographs—first because, as everyone knows, a print from an

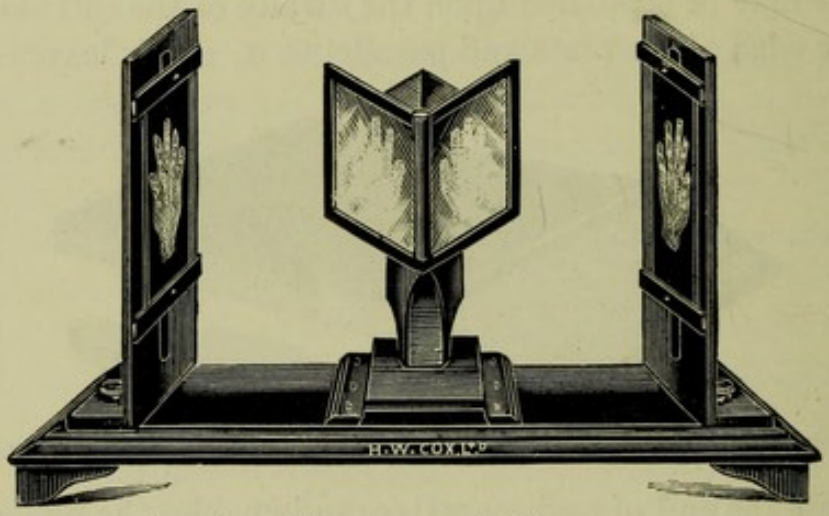


FIG. 167.—WHEATSTONE'S STEREOSCOPE.

X-ray negative is reversed; for example, if a skiagraph of a right hand be taken, when printed it appears to be a left hand. Now, if such a print be viewed in a Wheatstone stereoscope, it is reflected in one of the mirrors, and is thus reversed to its original position by the reflection. Therefore, if opposite the right mirror is placed the print from the negative produced when the Crookes tube was displaced to the right side, and opposite the left mirror the print from the negative taken when the tube was displaced to the left, the observer will then see the parts in correct stereoscopic relief, as if he had been looking at them with his eyes placed so that the right eye was at the point occupied by the anode when displaced to the right, and the left eye at the point occupied by the anode when the tube was displaced to the left. If the skiagraphs be viewed under the same angle as they were taken,

the stereoscopic picture would show the parts of the true or actual size, and the exaggerated distortion of the single X-ray photograph is overcome. The importance of such a result to a surgeon is great.

"There is no limit to the size of the pictures which can be viewed in a Wheatstone stereoscope. The largest size the writer has as yet taken stereoscopically is 12 by 15 inches.

"If the right picture be placed opposite to the left mirror, and the left picture opposite the right mirror, a stereoscopic picture will be seen as before, only reversed. For example, in one case a hand will appear as seen from the dorsal aspect; if the prints are transposed, it will appear as a hand seen from the palmar aspect. The same transposition can be effected by turning each print upside down."*

The negatives can be seen in a stereoscope if they are held in proper position, and are illuminated from behind. A pair of the lanterns described on p. 279 provide the best means of doing this.

The principle of the stereoscope can also be applied to screen work, and Mackenzie Davidson has devised an apparatus for the purpose which will be found described in the *Archives of the Roentgen Ray*, 1901, vol. v., p. 46.

Two similar X-ray tubes are arranged so that the distance between the two antikathodes is equal to the distance between the two eyes. As it is difficult to find a pair of tubes which are of similar quality, a double tube with two antikathodes may be used. By means of a commutator the tubes are illuminated in turn, so that they light up alternately at regular short intervals. The observer examines the screen through two openings which are kept opening and closing synchronously with the alternations of light and darkness of the tubes. Thus the right eye only sees the screen illumination caused by one of the X-ray tubes, and the left eye only sees the illumination caused by the other. These alternations follow one another with sufficient speed for the eyes to receive continuous impressions, and a stereoscopic effect is produced.

165. **Radium.**—This is a metal belonging chemically to the same natural group as calcium, strontium, and barium. Of this series it is the highest member, its atomic weight being 225,

* From the paper by J. Mackenzie Davidson in the *British Medical Journal*, January 1, 1898.

which places radium very high among elements of high atomic weight. It is found in minute amount in certain ores of uranium, and it is considered to be a product of the decay of that element ; but if so, it represents only a single stage, for it is itself unstable and in a state of change, passing through several stages, and forming another element—helium—of very small atomic weight.

Radium salts give a carmine colour to the Bunsen flame, and are self-luminous in obscurity.

The discovery of radium followed the observation of Becquerel that uranium and its compounds had the property of affecting a photographic plate through an opaque layer of black paper, a discovery which was prompted by Röntgen's discovery of the X-rays. It was found that pitch-blende, an ore of uranium, had an effect as powerful as that of pure uranium, though containing only 50 or 60 per cent. of that metal. Madame Curie drew the inference that this peculiarity might be due to the presence in pitch-blende of small quantities of some more active body, and after laborious researches in this direction finally discovered and isolated radium in 1898.

Radium is the most remarkable of a series of " radio-active " bodies, which includes also uranium, thorium, and perhaps others. Their existence is determined by the photographic method already referred to, or by the more delicate method of observing the rate of discharge of a charged electroscope when the radio-active body is brought near to it. This effect is due to their power of ionizing the air, and of rendering it a conductor of electricity. For methods of measurement of radio-activity Professor Rutherford's book* may be consulted.

Radium compounds emit three kinds of " radiation," known respectively as alpha, beta, and gamma rays. The alpha rays are positively charged material particles whose mass is computed to be twice that of the atom of hydrogen. They are now known to be atoms of helium.

A very good account of radium will be found in a paper by Mr. F. Soddy in the *Journal of the Röntgen Society* for February, 1906, entitled " The Present Position of Radio-activity," and the following paragraphs are taken from an abstract of that paper published in the *Electrician* for January 6, 1906 :

" Two out of the three types of rays emitted by the radio-

* " Radio-activity," by E. Rutherford, Cambridge University Press.

active elements—known as the β and γ rays—are substantially of the same nature as those emitted by a Crookes tube. Thus, the β ray is the familiar electron in motion, and corresponds with the cathode ray, while the γ rays result from the β rays in much the same way as the X-rays result from the cathode rays. The difference is that the X-ray bulb acts under the action of a constant supply of external energy, and ceases to work the moment the supply fails, whereas the radio-elements are entirely independent of external stimulus or supplies of energy. In the resemblance between the β and γ rays and the cathode rays and X-rays of the Crookes tube there is an important difference. The electron which constitutes the cathode ray travels ordinarily at a speed about one-tenth that of light, whereas the β rays of uranium travel with a speed about seven times greater. Like the cathode rays, the β rays are deviated by a magnet, but with much greater difficulty. Some of the β rays of radium have been shown by Kaufmann to have a velocity of 95 per cent. of that of light. So, too, with the γ rays. These, although strictly speaking X-rays, are so penetrating that, in passing through the hand, for example, there is so little absorption that the bones cast practically no shadow. Rutherford has shown the effect on an electroscope of the γ rays from 30 milligrammes of radium bromide after passing through a foot thickness of iron.

"An instructive difference exists between the γ rays and the X-rays. In the Crookes tube the electrons are gradually started and suddenly stopped, and although theoretically X-rays should accompany both start and stop, the latter only are penetrating enough to get outside the glass tube. In the radio-elements the β-ray electron is suddenly started, and we have seen that it is so penetrating that even the densest matter cannot suddenly stop it. But the acceleration experienced by the β-ray electron expelled in the disruption of the radio-atom is the most sudden known, and in consequence the γ rays are by far the most penetrating type of X-ray known. The α ray is scarcely able to penetrate the thinnest sheet of paper, mica, or aluminium, and is completely absorbed in 7 centimetres of air. It is deviated very slightly by the action of a magnetic field, and the deviation is in the opposite sense, and only about one-thousandth as great as that which would be experienced by a β ray under similar circumstances. Rutherford concluded that the α ray was a

radiant atom, minus an electron, or positively charged, and that it travelled with a speed about one-tenth that of light. The most recent results point unmistakably to the conclusion that the particle is, in fact, an atom of the element helium.

"The recognition that the expulsion of the α, β, and γ rays is the outward and visible sign of a deep-seated material change continuously occurring within the atoms of the radio-elements began with the clear elucidation of two other phenomena exhibited by certain of the radio-elements—namely, their power of producing a radio-active emanation, and the power of the latter to impart radio-activity to surrounding objects. These powers are shown by thorium, radium, and actinium, but not by uranium or polonium. In addition to their radiations, each of the elements first named continuously produces what have been clearly shown to be new radio-active gases, now generally called 'emanations.' The thorium emanation was first discovered by Rutherford, and the recognition of the other two quickly followed. This emanation from the radio-element has been proved to be produced in the same constant amount under all circumstances. Under some circumstances the production is more obvious than in others, for certain of the solid compounds possess the power of retaining and storing up the gaseous emanation, and so preventing its escape into the air. This does not occur with a solution. The emanations have the same essential features, but differ among themselves in detail. After its production from the radio-element, the radio-activity of the emanation continuously decays with time according to a regular geometrical law. The activity of the emanation from actinium decays to one-half of its initial value after the lapse of only four seconds. The same occurs in the case of the thorium emanation in about a minute, and with the radium emanation in four days.

"All three emanations possess the extraordinary power of imparting to inactive solid objects in the neighbourhood a new and distinct type of temporary activity. This 'imparted activity' decays also according to regular laws, which are characteristic and distinctive in each case for the different elements from which they are derived. This process has been elucidated and shown to be due to a change occurring in the gaseous emanation. Gradually and continuously it turns into a new type of radio-active matter, non-volatile, and so depositing itself as a film upon any

solid object available. The films are invisible and unweighable, and are only known by their activity. Nevertheless, if such a surface, rendered active by exposure to the emanation, is scrubbed with sand-paper, the film is removed, and the activity is then found on the sand-paper.

" In consequence mainly of these and allied phenomena, the view was put forward in 1902 by Professor Rutherford and Professor Soddy that the radio-elements were in a state of continuous and spontaneous change, capable of an exact quantitative expression, and that the emanations and allied bodies were the products of these changes.

" We have seen that radio-activity is a property intrinsic to the element, and, therefore, to the atom or smallest part of the element. The radio-elements possess the heaviest known atoms. If the lightest (hydrogen) is taken as unity, uranium is 238, thorium 232, and radium 225, while the next heaviest known are the inactive elements—bismuth 208, and lead 207. The element helium is the second lightest known, and its atomic weight is 4. If the α particle is an atom of helium, the expulsion of one α particle from an atom of radium will reduce its atomic weight from about 225 to 221. This must, therefore, be a new atom, and represent an unknown element, for we have seen the nearest known element has the atomic weight 208. Now, it is known that the chemical elements run in families. Radium, for example, is the missing ' big brother ' of the alkaline earth family of elements, which consists of three elements—calcium 40, strontium 87, and barium 137—and chemically radium is an almost exact copy of its nearest relation, barium. Helium, in turn, is the lightest member of a family of gaseous elements, exactly similar in chemical nature. The family forms the well-known group discovered by the joint labours of Lord Rayleigh and Sir William Ramsay. The series runs—helium 4, neon 20, argon 40, krypton 82, and xenon 128. It happens that the heavy residue of the radium atom possessing an atomic weight of about 221, left behind after the expulsion of the light helium atom, turns out to be one of the missing ' big brothers ' of helium itself, being nearly twice as heavy as the heaviest (xenon) previously known. It is new, and a gas of the same chemical nature as the others, and is produced at a steady rate from radium—one atom for every α particle expelled. It is, in fact, the radium emanation.

"A quantity of radium, although it is sending forth its shower of α particles continuously from year to year, does not grow appreciably less. The most sensitive balance has not yet succeeded in showing any change of weight. Hence, it is obvious that, although the actual number of α particles and of new atoms of emanation may be—indeed, must be—enormous, they only represent an unrecognisably small fraction of a minute amount of radium. The radium atom turns into a new atom—the atom of the emanation—by expelling an atom of helium. If the emanation expels another helium atom, another new residue atom of weight 217 will be left. This is the solid form of matter which is deposited as a film from the emanation, and is the cause of the phenomenon of the imparted activity. It is called by Rutherford radium A, and it also is recognised solely on account of the α particles it expels. So the residue from radium A is another new atom of weight 213 ; it is called radium B. Rutherford, as the result of a series of observations elucidated with consummate skill, has recently arrived as far as radium F in the analysis of the later slow changes of radium. But an α particle is not expelled in each case. Sometimes it is the β ray or electron only, as in the case of the change of radium E into radium F ; sometimes no radiant particle is expelled at all, and we have a rayless change, as, for example, when radium B turns into radium C ; but then the next change—that of radium C into radium D—makes up for this by expelling both α and β particles. Reverting to radium F, we find it also gives an α particle, and so must change into a radium G. Now, radium F—the seventh successive product of the disintegration of radium—has been shown to be the polonium of Madame Curie, found by her as a constant companion of radium in the uranium mineral pitchblende. Polonium gives α rays, but no detectable other product. We have at length reached the apparent end of the process. Radium G does not expel either α or β particles, and so we have only a theoretical reason for believing it to exist. We can, however, make a good guess as to what radium G is. Counting the total number of helium atoms expelled in the series, we find they amount to five, or a loss of the atomic weight of 20 units, which leaves a residue about 205. Now, remembering that the atomic weight of radium is uncertain to at least a unit, and that, if anything, the atomic weight of helium is likely to be less than four, you will see that lead (207) might

well be radium G. This is as much as can be said for the moment.

"Not only have the chemical and physical characteristics of these intermediate forms of matter produced in the successive break-up of the radio-elements been determined—and they exhibit a strange diversity—but also the period of average life of the atom in each case. This latter is the most characteristic constant by which the numerous forms may be distinguished. It was thus that polonium was shown to be radium G. The average life is got from the rate of decay of the radio-activity. A definite proportion of the total number of atoms present undergoes disintegration per second, and in consequence the number present diminishes after removal from the parent element, and the activity correspondingly decays. Thus, in the case of the thorium emanation, it can be readily calculated that about one eighty-seventh part of the total number of atoms expel α particles and change per second, so that the period of average life of the atom of the thorium emanation is 87 seconds. Similarly, for the radium emanation atom only one five hundred thousandth disintegrates per second, so that the period of average life is 500,000 seconds, or 5·3 days.

"Thus, if solutions of radium and thorium are contained in closed bottles, the amount of emanation accumulating in the bottle containing the thorium will reach its maximum in a few minutes, and after that, however long the bottle is kept closed, no more emanation can accumulate, for as much disintegrates per second as is formed per second. But in the case of the radium solution the quantity accumulating will go on increasing daily, and the maximum or equilibrium amount will not be reached until some weeks after the bottle is closed up.

"When, however, the end of the disintegration series is reached, since the ultimate product is not changing, the quantity accumulates without limit, and, provided that you are able to wait sufficient time, you will ultimately obtain enough to detect by ordinary chemical analysis. But in most cases centuries would have to elapse for this to occur. Fortunately, there is an indirect method of obtaining evidence of the nature of the ultimate products. These processes have been going on continuously during past ages in the earth, so that, if we track the disintegrating element to its natural source, the mineral in which it occurs, we shall expect to find there the ultimate products of

ages of past accumulation. The short-lived, the long-lived intermediate forms, and the final stable products, will all exist in recognisable quantity in the natural mineral, as the invariable companions of the radio-element. Thus, long before the production of helium from the radio-elements was established experimentally, helium was clearly indicated as one of the ultimate products of radio-active change, because it is always found in the minerals which contain the radio-elements, and only in those minerals. We recognise radium, polonium, and lead also as constant companions of uranium. The average life of the radium atom is of the order of 1,000 years, and of the polonium atom about seven months. If we suppose that radium and polonium are two long-lived intermediate forms in the disintegration series of uranium, the difficulties already raised in connection with the continued existence of these elements at the present time disappear. This view has now been experimentally proved. The growth of radium in solutions of uranium completely freed from it has been observed. In addition, it has been established for all the uranium minerals that the ratio between the proportion of uranium and radium is constant. We have seen that radium disintegrates approximately a million times faster than uranium; so that, after the lapse of only a few thousand years, the radium present in a uranium mineral will attain the equilibrium ratio. As much will disintegrate as is produced from the uranium in its disintegration. As the latter process occurs about a million times more slowly than the former, the equilibrium ratio will be about one part of radium to a million of uranium. The exact amount experimentally found is 0·72 gramme of radium per ton of uranium. The identity of radium G and lead still remains unproved. In addition, the existence of several intermediate forms of long life between uranium (238) and radium (225) has been indicated, and are now being sought for.

"The discovery that the proportion of radium in the naturally occurring uranium minerals is a fixed constant, so that, if the percentage of uranium is known, the quantity of radium can be calculated, has opened out a vista of new possibilities. A few thousand years hence the small quantity of radium here to-night will have had its day and cease to be. But if it were then possible to examine the uranium from which it was originally separated, it would be found that a new quantity no less in amount had grown in the interval, exactly as a closed bottle containing

radium grows a new crop of the emanation again, however many times the emanation is removed."

Radium has been applied to the treatment of the conditions for which X-rays have been found useful. It has been successful in cases of rodent ulcer and in lupus. It is applied by means of glass tubes containing five or ten milligrammes of radium bromide, which are held or fixed close to the affected part. It is also enclosed in small capsules with a cover of mica, which permits of the escape of beta rays to a small extent, as well as of the gamma rays.

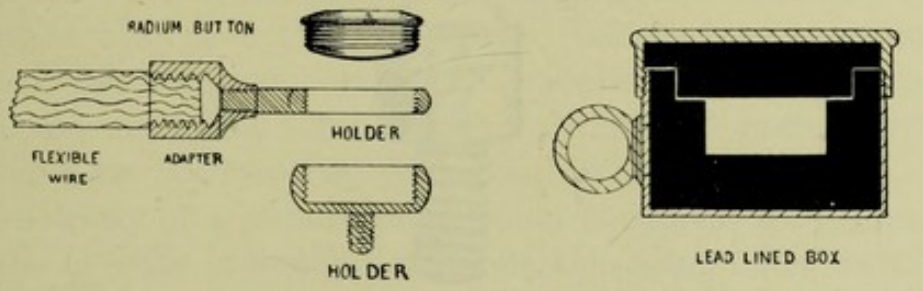


FIG. 168.—RADIUM BUTTON.

Messrs. R. and J. Beck put up radium in small "buttons" (Figs. 168 and 169) of a convenient kind. They are made to contain ten milligrammes of radium bromide, the front of which consists of an aluminium casing $\frac{1}{100}$ inch thick. Behind the radium is placed a backing of lead $\frac{1}{10}$ inch thick. The outside

FIG. 169.—BUTTON IN HOLDER (ONE-FIFTH SIZE).

of the button has a screw thread, by which it can be placed in holders which are sufficiently small for insertion in the nostrils, larynx, etc.

A brass box is supplied, lined with lead $\frac{1}{5}$ inch thick, in which the button may be kept. A ball-shaped wooden handle is also supplied, to which the button, protected by a lead cup, may be

attached, so that it may be held with the aluminium cover against the skin, either in contact or at a small distance away.

When the small holders are used for inserting in the nostrils or other orifices, they may be screwed by means of an adapter upon a flexible stem, which can conveniently be improvised from a piece of gutta-percha-covered electric cable about $\frac{1}{4}$ inch diameter, bent into any required shape.

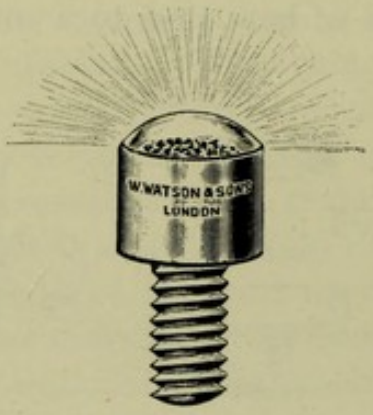


FIG. 170.—HARTIGAN'S RADIUM APPLICATOR.

Mr. Hartigan encloses the radium in a small metallic capsule, with a front of quartz of rounded shape. The capsule is fitted with a screw thread for attachment to holders of various shapes to permit of the application of the radium to hitherto inaccessible situations—*e.g.*, œsophagus, larynx, bladder, etc. It is practically the size of a No. 12 catheter.

Attempts have been made to utilize the radio-activity of the cheaper thorium compounds for medical purposes, as radium salts are expensive and difficult to obtain. There is also a very important difference between the properties of radium and thorium, rendering the latter more suitable for the purpose in view; for if the emanations from a radium solution be removed from it, the radium will require three weeks or so to regain the amount lost; but in the case of thorium a few minutes only are required for complete restoration. When the emanations come in contact with any surface, they leave behind a film of radio-active matter, the activity of which disappears at a definite fixed rate.

Mr. F. Soddy has suggested an apparatus for the inhalation of the thorium emanation, for use in pulmonary disease. This consists of a glass apparatus containing a strong solution of thorium nitrate, and connected by rubber tube to a drying tube

containing a few pieces of potassium hydroxide. Taps can be supplied for regulating the current of air drawn through and for shutting off the thorium solution when not in use.

The air in passing through the solution carries with it the radio-active gas generated by the thorium nitrate. This is drawn slowly into the lungs by inhaling through the mouth-piece.

Bouchard, Balthazar, and Curie have shown that the much more potent radium emanation gives rise to toxic symptoms when inhaled, the dominant lesion being an intense pulmonary congestion. Water through which radium emanations have been drawn has also been tried medically, and various substances, such as cotton-wool and platinum foil, have been exposed to radium emanations until they have acquired an induced radio-activity, and then have been applied to medical purposes.

The activity of a radium preparation is expressed in terms of the radio-activity of metallic uranium, this being taken as unity. Pure radium bromide is considered to be 1,800,000 times as radio-active as uranium, and can be purchased as a marketable commodity, the price quoted at the present time by M. Armet de Lisle, a French manufacturer, being 400 francs (£16) a milli-gramme. Most of the existing specimens of radium are mix-tures of radium and barium bromide, and their radium contents vary considerably. A good specimen should produce phos-phorescence on a screen of barium platino-cyanide through several copper coins, and should discharge an electroscope with ease at a distance of a yard or more. Radium bromide has the appear-ance of small crystals or granules of a yellowish-brown colour.

CHAPTER IX

PHYSIOLOGICAL CONSIDERATIONS

Electrolytic conduction—The resistance of the body—Cataphoresis—Diffusion of current in the body—The capacity of the body—The action of electrical currents on living tissues—The motor nerves and muscles—Unstriped muscle—Electricity as a test of death—Sensory nerves—Lethal effects—The brain.

166. **Conduction of Electricity by the Tissues.**—It has been said that the body is an electrolytic conductor, and the terms used in considering the portion of a circuit in which electrolytic conduction is taking place have been shortly given in § 19. When a battery or other source of direct current is connected to a patient by means of the usual moistened pads, a current flows through the circuit, because the wires, the moist pads, and the body are conductors. The mechanism, however, of the conduction in the non-metallic parts of the circuit is not the same as that which holds good for the wires. Conduction in watery solutions of salts (and the tissues of the body may be regarded as coming into this category) takes place only by the conveyance or transport of charged particles or "ions" through the liquid from one metallic terminal to the other, and without this movement of material particles there is no conduction in liquid solutions. The moving particles or ions are the result of the dissociation of the molecules of the salt by the process of solution, so that a solution of sodium chloride in water contains abundance of dissociated ions of chlorine carrying negative charges and of sodium carrying positive. When a current is applied, there is a double movement among these ions—a procession of the chlorine ions to the positive pole and of the sodium ions to the negative, every ion carrying its appropriate positive or negative charge, so that the measurement of the current by a galvanometer in the circuit gives an accurate indication of the number or amount of the chlorine ions

brought to the positive pole, and of the sodium ions brought to the negative.

This movement of ions has been very well illustrated by Leduc, who connected two rabbits in series by means of a pad soaked in saline solution. On applying to the skin of the first rabbit an anode moistened with strychnine sulphate, the kathode on the second rabbit being moistened with a similar solution, he found that only the first animal was affected by the alkaloid, which migrated into its body from the anode, while the second animal remained unaffected during the time of the experiment, the ions migrating into its body from the kathode being harmless SO_4 ions.

He then repeated the experiment with cyanide of potassium. In this case it was the rabbit at the kathode which was poisoned, the toxic constituent of the chemical used being the cyanogen ions migrating inwards from the kathode only.

The region between the poles shows no evidences of either free acid or free alkali, and yet it is certain that ionic exchanges are taking place all through the chains of molecules between anode and kathode. Moreover, the changes occur, not only in the fluids of the intercellular spaces, but also in the whole of the cell substance which is traversed by the current.

In the case of the ordinary electrodes used in medical treatment, the separation of the products of electrolysis takes place at the metallic surfaces—that is to say, in the moist chamois leather or other water-bearing material with which the electrodes are covered. These coverings, in fact, are made use of to absorb and, so to speak, to occlude the chemical products, in order to protect the skin from their action.

Uncovered electrodes would lead to injury of the skin, because with them the chemical products of the electrolysis are set free in immediate contact with the epidermis, and attack it. With prolonged applications, especially if the density of the current is great, the accumulated products of the electrolysis gradually diffuse through the coverings of the electrodes, and exercise their proper chemical action upon the surface of the skin. Undesirable caustic effects may easily be produced in this way, unless care be taken.

167. **The Resistance of the Body.**—The resistance of a patient's body, as observed clinically, is almost entirely a resistance at the contacts of the electrodes with the skin ; it can be varied in

many ways, and it does vary from day to day in the same patient.

Professor G. Weiss,* measuring the resistances from hand to hand with contacts made through bowls of salt water, found the average resistance in sixteen men to be a little over thirteen hundred ohms, and in seven women fifteen hundred ohms. The reason why the latter showed a higher figure is not very clear, but may have been due to the smaller surface of the hands of the women, or perhaps to a lesser number of sweat glands and hair follicles ; the difference, however, is not great, and would probably be less apparent if a larger number of cases had been measured.

When the electrodes are applied to mucous surfaces, or are in the form of needles thrust through the skin, the resistances are much lower. By a method which eliminated the skin resistance, Weiss found the tissue resistance from shoulder to shoulder to be no more than forty ohms, and from elbow to elbow two hundred and fifty ohms.

Leduc, interpreting the phenomena of skin resistance in the light of the laws of electrolysis, points out that the skin behaves as an electrolyte poor in ions. During the passage of a current there is a movement of ions outwards from the tissues of the body towards the electrodes, and inwards from the electrodes to the skin, and the resistance falls, at first rapidly, but afterwards more slowly, until it reaches a steady value. The final values differ for different ions ; the simpler ions—as, for example, those of chlorine or of sodium—showing a greater reduction in resistance than the more complex ions of calcium, of cocaine, or of cacodylic acid. If salt solution is used for moistening the electrodes, the resistance of the skin is much reduced, because it provides abundance of free ions to convey the current.

The medical practitioner is concerned with the resistance of the body mainly as it affects the question of treatment, and the number of cells required to drive the proper current through the patient. Under conditions of medical practice, and using salt water to moisten the skin and electrodes, the resistance of the body ranges about one or two thousand ohms—that is to say, an electromotive force of twelve volts (eight Leclanché cells) will pass a current of between six and twelve milliampères. On the palm of the hand or the sole of the foot the resistance will be at

* *Arch. d'Électricité Médicale*, 1893.

least double. Very high resistances may be observed in hospital patients who have been long confined to bed.

Careful measurements of the resistance of patients, and statements as to the degree of resistance in different morbid states, are not of much value or importance. Low resistances have been observed in Graves' disease, in which the skin is usually moist, and high resistances in hysteria, in melancholia, and in paralysed parts, in which it is dry.

During the progress of treatment the electromotive force in circuit which is employed at the commencement must be reduced gradually to compensate for the fall in resistance which takes place as the skin becomes penetrated by ions ; for if this is not done there is a risk lest the current should become larger than it is intended to be, and injury may result to the patient from want of attention.

During the course of an application the resistance of a patient's body may be calculated by Ohm's law from the galvanometer reading and the electromotive force of the cells, if that be known. For example, with six Leclanché cells in good order the electromotive force will be nine volts, and if the current through the patient be four milliampères, the resistance may be taken as follows :—$R = \frac{E}{C}$, $E = 9$ volts, $C = \cdot 004$ ampère, therefore $R = \frac{9}{\cdot 004}$ or 2,250 ohms. In this way an estimate quite close enough for most cases can readily be formed. When exact measurements are required, the Wheatstone's bridge method (§ 44) should be used. Professor Weiss's paper* indicates a method of overcoming the difficulties of polarisation when the battery and galvanometer method is used.

168. **Electrolytic Effects.**—The electrolytic effects produced by currents are most apparent when needles plunged through the skin are used as the electrodes. This procedure is employed in medical practice as a means of destroying tissues.

At the kathode the alkali metals formed in the first instance react with the water to form caustic alkali and liberate hydrogen, which appears as bubbles of gas. The caustic potash or soda thus produced destroys the tissues with which they come in contact, producing a soft deliquescent eschar. At the anode acids with chlorine and oxygen are formed, but the secondary reactions which take place there depend very much on the com-

* *Vide supra.*

position of the anode. If the electrode is made of zinc, chloride of zinc is formed, which exerts its own specific action on the tissues. By using anodes of iron or copper, the local effects of salts of these metals can be observed. By means of electrolysis these caustic effects can be obtained in parts difficult of access, as the male urethra, or uterine cervical canal, the larynx, pharynx, or nasal duct, where the application of other caustics is attended with danger or difficulty. The effects are limited to the points touched by the electrode, and the degree and extent of the caustic action is entirely under the control of the operator.

169. **Electrolytic Medication.—Cataphoresis.**—A movement of the electrolyte comparable to osmosis takes place under the influence of a current, and generally occurs in the direction of flow of the current—namely, from the positive to the negative pole ; fluid can in this way be made to pass through membranes or porous diaphragms against the force of gravity. It has been proposed to make use of this process for the introduction of drugs into the body through the skin, but the migration of the ions referred to in § 166 is a more important factor in the percutaneous introduction of drugs by means of electric currents.

Electrolytic or cataphoric medication is a more complicated procedure than the administration of drugs by the mouth or by hypodermic injection, and it must have some corresponding advantages if it is to be adopted into medical practice. For purposes of local medication there might be a field of employment for electrolytic applications ; for whereas a hypodermic injection passes into the interstices and lymph spaces, and may not penetrate the cells of a part, the ions introduced electrolytically must enter into the composition of every cell through which the current penetrates. The principles underlying the electrolytic introduction of drugs are as follows : If the body to be introduced through the skin be a kath-ion or positively charged ion, it will migrate from the anode, and the substances which enter from the anode are the ions of the metals, of the alkalies and alkaloids, and of other bases ; while from the kathode the various acid radicals are introduced. Thus, in order to introduce ions of zinc into a given area, the proper procedure is to apply a pad of lint or of cotton-wool moistened with a solution of a zinc salt and to bring to the outer surface of the pad a rod or plate of metallic zinc connected to the positive pole of a battery. The current which flows is carried by the zinc ions of the solution which

migrate inwards through the skin, and, their number being renewed by fresh zinc ions set free from the electrode, there is no fear of exhaustion of the supply, or of the contamination of the pad by ions of other metals, as would be the case if a different metal were used for the electrode. When the substance to be introduced is one like quinine or salicylic acid, the supply of its ions must be maintained by the provision of an ample quantity of its solution in the fluid of the moistened pad, and the metal of the electrode should be of platinum, in order that extraneous ions may not complicate the process. Carbon discs or plates, if thoroughly pure, may be used instead of platinum, as carbon liberates no ions under the conditions of the experiment.

If it can only be established by further experiment that electrolysis provides an effectual mode of percutaneous local medication, its applications in medical practice may become numerous. It is historically interesting to recall the fact that Benjamin Ward Richardson made many experiments in the production of local anæsthesia by the introduction of aconite in 1859, but his work met with so much opposition and incredulity that he was forced to give it up. More recently, the discovery of cocaine has enabled the production of local anæsthesia by electrolysis to be carried out with greater success, and I have used this procedure frequently before removing moles and small papillomata by needling.

Edison, in 1890, suggested electrolysis for the introduction of lithium into gouty tissues, and since his time several medical experimenters have noted the good effect of this form of treatment. Quite recently Bordier repeated these experiments, also using as electrode a bath containing a solution of lithium, and made a series of applications to a patient with large gouty deposits in the hands. He was not only able to demonstrate the presence of lithium in the patient's urine, as had been done before by others, but—and this is even more striking—he detected the presence of uric acid in the liquid of the arm-baths, thus proving both the introduction of the kathion lithium and the extraction of the anion uric acid at one operation. There was also a marked change for the better in the condition of the patient's gouty deposits as a result of the experiments.

170. **Diffusion of Current in the Body.**—When a current is led into a broad conductor the lines of flow spread out through the conductor. The current which passes across unit of sectional

area taken at right angles to the lines of flow at that point may be called the density of the current at that point.

In a conductor like the human body it may be necessary to take into consideration the density of current at any particular point, because the physiological effects are partly dependent upon the density—that is, upon the ratio of current to sectional area.

The path of a current between two electrodes placed upon the body surface is not to be marked out simply by drawing direct lines from the one to the other, for the whole of the conducting tissues between the electrodes help to provide a passage for the current, which spreads out from beneath the positive electrode, becoming less and less dense as it occupies a wider and wider sectional area of the conductor, and again grows denser as its lines of passage become once more gathered together to reach the negative electrode.

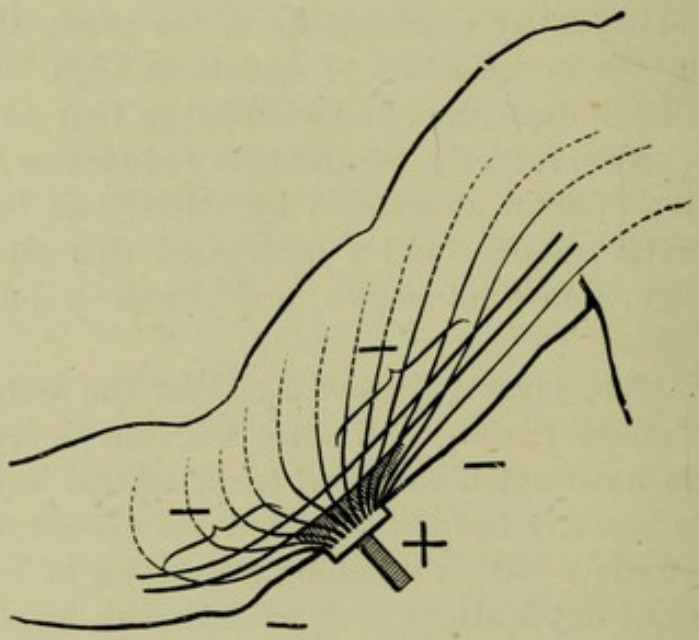


FIG. 171.—LINES OF CURRENT DIFFUSION ROUND POSITIVE ELECTRODE PLACED OVER THE LOWER PART OF THE ARM.

Fig. 171 shows roughly the divergence of the directions of these lines of current as they pass from a positive electrode placed upon the back of the arm to reach the negative electrode placed somewhere upon the trunk, and it very well illustrates the fact that the current is not confined to the space directly between the electrodes, for some of the lines which indicate its direction actually commence their course by curving downwards through the tissues below the electrode.

It also follows that the size of the electrodes is of importance

in treatment, for at the surface of contact of a small electrode the density of current per unit of surface, when a definite quantity of current is flowing, will be greater than when large electrodes are used.

171. **The Capacity of the Body.**—The human body regarded as a simple homogeneous conductor should have an average capacity, calculated from its extent of surface, of 0·000044 of a microfarad. Many experimenters who have examined this difficult question have found that the measured capacity is greater than this. It appears almost certain that the increase is to be attributed to polarization effects of an electrolytic character, comparable to those which occur in a secondary cell or storage battery. The existence of this electro-chemical capacity has been established by Weiss, and measurements of the actual capacity of the body have been made by many Continental experimenters. Thus Bordier estimates the capacity of the body at 0·0025 microfarad, Dubois at 0·165 microfarad, Wertheim Salomonson at 0·0002 nearly, De Metz at 0·0001. There is a considerable discrepancy between these values, and this may be due to the different methods employed, if we suppose that the capacity varies with some other factor, as, for instance, with the electromotive forces applied during the operations for measuring its magnitude.

A very instructive account of the methods of measurement employed by different experimenters will be found in Professor Castex's recent book, from which this paragraph is mainly derived. In one of the experiments of Wertheim Salomonson there detailed, the influence of the capacity of the body upon its apparent resistance to high-frequency currents had the effect of reducing the value to 373 ohms, although the resistance when measured by a direct battery current had a value of 2,000 ohms.

The influence of the capacity of the body in high-frequency work is further illustrated by the following experiment: Four persons, hand in hand, were connected to one pole of a high-frequency apparatus, and the current was measured. Between the pole of the apparatus and the first subject a current of 151 milliampères was registered; between the first and second the current was 132; and between the second and third 128 milliampères.

172. **The Motor Nerves and Muscles.**—The behaviour of nerve and muscle to electrical stimuli under conditions of experiment

with dissected tissues is dealt with in works on physiology. In the living subject the phenomena observed under conditions of electrical testing and treatment are as follows: If with the indifferent electrode (§ 68), placed upon any convenient part of the surface of the body, the testing electrode (Fig. 54) be applied over a superficial motor nerve, as the ulnar at the elbow, it will be found that muscular contractions begin to be visible at closure of the circuit with a current of 1 milliampère from a battery, and with stronger currents contractions appear both on closing and on opening the circuit. With the active electrode negative the contraction at make or closure is easier to produce than when it is positive. The order in which they appear are:

1. Kathodal closing contraction (KCC).
2. Anodal ,, ,, (ACC).
3. Anodal opening contraction (AOC).
4. Kathodal ,, ,, (KOC).

The symbols affixed are commonly used for convenience to designate the contractions.

The smallest current needed to produce a muscular contraction by the stimulation of a motor nerve trunk varies with different nerves. A nerve which is superficially situated responds to a smaller current than a deep-seated one, because it receives a greater fraction of the current. In the case of a deep-seated nerve the current is scattered by diffusion, and only a part of the current indicated by the galvanometer traverses it effectively. For the same reason a patient with a thick layer of subcutaneous fat requires a larger current to provoke muscular contractions than is the case with a lean person in whom the electrode can be brought into closer proximity to the nerve to be stimulated. The testing electrode should be of small surface, as this allows us to concentrate the current more effectively.

It has lately been shown by Dr. Ludwig Mann of Breslau that the nerves of infants and young children require currents of considerably greater magnitude to provoke contraction in their muscles.

In a normal muscle the effect of direct stimulation of its fibres is overshadowed by the effect produced upon it through its nerves, for the intramuscular branches of its nerves both receive the impression better, and transmit it to all parts of the muscle more rapidly than the muscular fibres themselves could do if no nerves were present. Still muscle *per se* is irritable and

capable of responding to stimuli by a contraction, and a muscle whose nerves have undergone injury may still respond to currents directly applied, although unaffected by stimuli applied to its motor nerve.

The effect of curare in rendering the muscles inexcitable through the motor nerves has long been known. It was discovered by Claude Bernard. In a curarized animal stimuli applied directly to the muscles are able to produce contractions, though stimuli applied through the motor nerves are not. A curarized muscle will react to interrupted currents as well as to battery currents, and the contractions produced only differ from those of a normal muscle in being a little less brisk.

Strophanthine also modifies the muscular contractions. When injected into a frog, it predisposes to the production of duration tetanus, so that a steady current easily provokes a tetanic contraction, which may persist after the current has ceased to flow.

Mlle. J. Ioteyko,* in her researches into the behaviour of muscle under electrical stimulation, has shown that all muscle contains two kinds of material—the striated portion and the sarcoplasm ; that both of these elements are contractile, but in different degrees, the former being capable of responding to brief stimuli and contracting rapidly, the latter requiring stimuli of longer duration and contracting slowly. In different types of muscle the relative amounts of each component are different, and different muscles therefore contract at different rates.

The tonicity of a muscle is the expression of the action of its sarcoplasmic element. The contractile power of the sarcoplasm reinforces the effect in all continued muscular efforts. The effect of certain drugs, such as veratrine, in altering the shapes of the muscle curve, is due to an action in heightening the excitability of its sarcoplasmic elements, and the somewhat similar influence of fatigue upon the muscle curve is due to the more rapid rate at which the striated portion becomes fatigued, this permitting of the observation of a preponderating action of the sarcoplasm. Finally, the " sluggish contraction " of muscles observed in certain morbid conditions is a contraction of the sarcoplasmic elements, which persists when the striated portion is thrown out of action by disease.

The contractions produced in muscle by the stimulus of the make and break of a direct current are momentary single contrac-

* " Études sur la Contraction Tonique du Muscle Strié," Brussels, 1903.

tions, and between the contraction at make and the contraction at break the muscle appears quiescent and relaxed, although the current is traversing it. As a matter of fact, it is not completely relaxed, and a small "contraction remainder," perhaps due to the sarcoplasm, can be observed by appropriate methods of investigation, and the larger the currents the greater will this degree of contraction be. With strong currents a condition of imperfect tetanus is produced, which has been named "duration tetanus." Duration tetanus is not usually seen in healthy muscles with the currents used in electrical testing, but in certain altered conditions it is more readily elicited than in health, and may have some diagnostic importance.

173. **Interrupted Currents.**—If the makes and breaks of a battery current follow one another in rapid succession, the muscle passes into a state of tetanus or permanent contraction. To produce this effect the individual shocks must succeed one another at the rate of twenty per second or upwards.

As the discharge from an induction coil consists of a series of impulses or waves of current (§ 48) occurring about fifty times a second, it is reasonable to expect that their effect upon a motor nerve would be to throw the muscles into a tetanic contraction, and that is what is observed. If the induction coil be arranged to give single shocks, single contractions follow, exactly like those produced at the closure of a battery current, each wave of current from a coil acting as a separate stimulus, but ordinarily the effects are fused by the comparative slowness of the muscular contraction, which requires one-tenth of a second for its completion.

In practical electrical testing it is usual to apply the electrodes to the muscles directly at their motor points, whose position will be indicated later. The individual behaviour of the muscles is more clearly seen by this method than if they be thrown into contraction in groups, as generally happens with stimuli applied to a nerve trunk which supplies a number of separate muscles.

The study of the effect of electrical stimuli upon nerve and muscle has been complicated by the adoption of the induction coil as the usual source of interrupted currents. Induction coil discharges are impulses of irregular form and variable duration, and are by no means the instantaneous discharges which they have been too commonly assumed to be. In recent years the exact character of the electrical stimuli used in electrical testing

and treatment has attracted some attention. Hoorweg, Dubois, Huet, Mendelssohn, and others, have attacked the problem in various ways, but there is still much work waiting to be done. D'Arsonval throughout all his researches has insisted on the importance of the form of the wave of an electric impulse in any study of its physiological effect. Dubois has shown that comparatively slight alterations in the self-induction of a circuit exercise a marked effect upon the current required to provoke the minimal contraction in a muscle, simply through altering the wave form of the current by retarding its rate of rise. Leduc* has told us that currents interrupted mechanically are superior to those of an induction coil for purposes of diagnosis and treatment, because the impulses can be regulated as to both frequency and duration, and can be exactly measured, while the shapes of the individual impulses can also be exactly determined (Fig. 42). Leduc's apparatus is described and illustrated in § 63, and is beginning to come into practical use. It is only a matter of time for interrupted currents of this kind to supersede induction coil currents in scientific work.

The effect upon nerve and muscle is most easily obtained when the impulses occur one hundred times a second and consist of waves each having a duration of one thousandth of a second, followed by a period of no current lasting for the remainder of the period (nine thousandths of a second). If the durations of the individual waves are either reduced or increased the electromotive forces necessary to set up a minimal contraction become larger, although there is no very great difference until the change in the duration is considerably altered, as may be seen from the annexed table taken from Leduc's paper :

Duration of Impulse. Seconds.	E.M.F. necessary for Minimal Contraction. Volts.	Duration of Impulse. Seconds.	E.M.F. necessary for Minimal Contraction. Volts.
0·00001	22·0	0·00100	7·0
0·00010	15·0	0·00200	7·5
0·00020	13·5	0·00300	8·0
0·00030	12·0	0·00400	8·5
0·00040	11·5	0·00500	9·0
0·00050	10·5	0·00600	9·5
0·00060	9·5	0·00700	10·0
0·00070	9·0	0·00800	11·0
0·00090	8·5	0·00900	12·0

Number of impulses per second = 100.

* S. Leduc : " Étude sur les Courants Intermittents de Basse Tension," *Arch. d'Élect. Médicale*, September 15, 1903.

In proportion as the duration of flow decreases, so the current necessary to set up a contraction becomes greater, and for periods of flow which are infinitely short even large currents are unable to cause any excitation of muscles or of nerves.

If the intervals of no current are made very brief, the effect ceases to be that of a tetanizing current, and the interrupted current gives contractions like those produced by the closing of a continuous current. Thus, it happens that, when the intervals become very short, an intermittent current acquires the properties of a continuous current.

From what is known of muscular contractions in morbid states, we may expect that measurements of the duration of the periods of flow of an intermittent current might be used as a means of estimating the extent of disease in the nerve or the muscle, for in proportion as degeneration progresses in a muscle, so does it require longer and longer periods of flow before responding with a contraction. But hitherto no measurement of these durations has been obtainable.

174. **Condenser Discharges.**—Condenser discharges have also been used as stimuli to nerve and muscle. Boudet de Pâris, in 1888, advocated their employment, and in his book points out that condenser discharges cause little or no fatigue in muscle, and he also gives plans of the arrangement of a condenser apparatus for muscle testing. Hoorweg* also gives an account of the mode of employment of condensers. Dubois,† in considering the behaviour of muscle and nerve to condenser discharges, states that experiments with condenser discharges show that, as the charging potential is increased, the required capacity of the condenser decreases rapidly. For example, the minimal contraction in the muscles of man is obtained with a capacity of 0·48 microfarad charged at 12·6 volts, with 0·017 at 35 volts, and with 0·007 at 70 volts, the capacity in the last example being seventy times less than in the first, while the potential is only six times greater. In man a minimum potential of about 12 volts is necessary, and discharges at lower potentials are ineffective, whatever the capacity of the condenser. If the energy of the condenser discharges be calculated, it appears that at low potentials it is relatively large ; that as the potential is raised, and the capacity is diminished, the energy required

* "Recherches sur l'Excitation Électrique des Nerfs," Haarlem, 1899.

† *Rev. Internat. d'Électrothérapie*, August, 1900.

becomes less, until a point is reached, after which it again increases ; there is a relation between potential and capacity, such that a point can be found at which the minimal contraction is produced with a minimum expenditure of energy. Energy is wasted in the case of the large condenser at low potential, because much of the discharge is below the effective minimum ; while in the case of a small condenser and a high potential

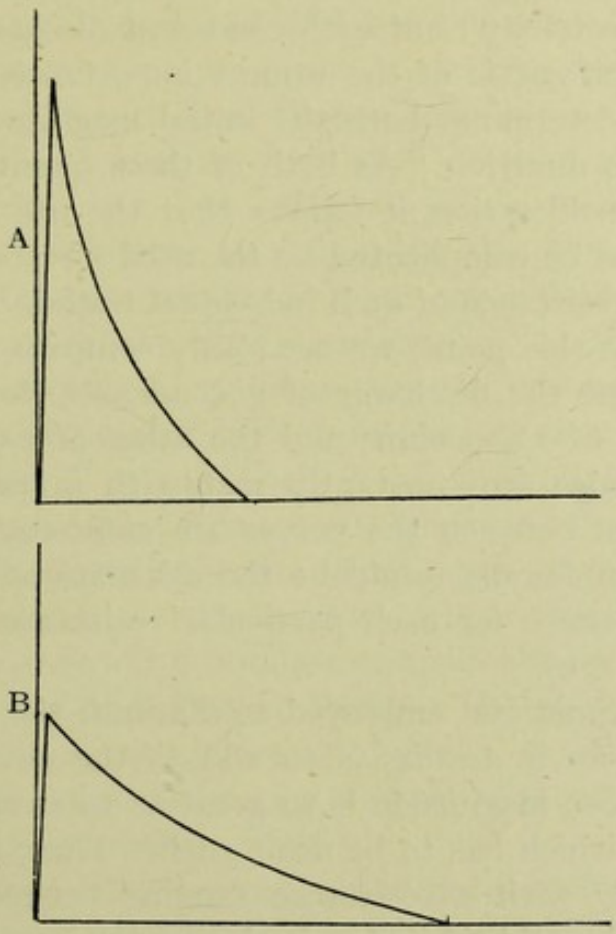


FIG. 172.—CURVES OF DISCHARGE OF A CHARGED CONDENSER.
A, Through a resistance of 1,000 ohms ; B, through a resistance of 2,000 ohms.

there is waste, because the duration of the discharge is too short.

In the case of a large capacity and a low potential, the rate of discharge may also be too gradual to be effective, owing to the resistance of the patient. The discharge of a Tesla coil fails because the individual impulses, of which it is made up, have too short a duration.

Dubois's experiments appear to emphasize the relationship between the wave form of the stimulus and the physiological

effect. The discharge of a small condenser at a high potential is a peaked sudden wave of short duration ; that of a large condenser at low potential is a wave of lower peak and long duration. The former is the more effective stimulus, unless, as in the case of the high-frequency apparatus, its duration is so short as to leave the nerve or the muscle uninfluenced.

Condenser discharges have the advantage that a known capacity, when charged to a known voltage, contains a known quantity of electricity ; but with condenser discharges the resistance of the circuit is of the utmost importance, for it is the factor which determines both the initial magnitude of the discharge and its duration. As both of these quantities must be taken into consideration, it follows that the use of condensers in testing must be complicated by the need for precise measurements of the resistance of each individual tested.

To illustrate this point, we need only compare two diagrams which represent the discharge of a condenser through two resistances, one of 1,000 ohms and the other of 2,000. Both of these magnitudes are constantly met with in practical work. The differences between the curves are sufficiently striking to show how troublesome would be the calculations to determine the shape of curve for each particular resistance met with in practice (Fig. 170).

A method sometimes employed to diminish the effects of unequal resistances in testing is to add to the circuit a further resistance, whose magnitude is so great as to swamp the range of variability which has to be dealt with. Thus, in the case of a human body with a resistance ranging between 1,000 and 2,000 ohms, the addition of a fresh resistance of the order of magnitude of 100,000 ohms would cause the variations met with in individual patients to sink into comparative insignificance. But if this method is tried with condenser discharges, the whole curve of discharge tends to become so long as to be unsuitable for diagnostic work as at present arranged.

175. **Unstriped Muscle.**—The behaviour of unstriped muscle differs from that of striped in that its latent period is much longer, and the rate of contraction is also longer. When the muscular coat of the intestine is stimulated, it may contract locally, and remain contracted for a time, or waves of peristaltic contraction may start from the point stimulated and travel slowly towards the remoter parts of the bowel. It is said that

the anode is the more effective pole for stimulating unstriped muscle. Unstriped muscle responds feebly to interrupted currents of brief duration, and the most effective means for setting up contractions in an organ containing unstriped muscle is to use the battery current slowly made and interrupted.

176. **Heart Muscle.**—The habits of heart muscle are peculiar in their highly developed tendency to rhythmic contractions. Electric stimulation tends to strengthen the action of heart muscle if it be timed to suit the natural rate of the rhythm. If the stimulation does not quite keep time with the heart-beat, it may effect a gradual change in its rate, until the heart may be brought to beat in time with the rate of the stimulation. If the stimulation be quite out of step with the rhythm of the heart, it will tend to embarrass its action. A weak or moderate continuous current or a smooth unbroken succession of induction-coil shocks may strengthen or accelerate the beat of the heart. Strong continuous currents destroy the rhythm of the heart, and cause it to stop in diastole (see below, § 182), and a succession of strong shocks from an induction coil do the same. The useful employment of electricity to strengthen a heart which has suddenly developed signs of failure is very difficult, and there is considerable risk of doing the patient more harm than good by injudicious applications.

177. **Electricity as a Test of Death.**—The electrical reactions of muscle afford a complete test of death, as the contractility of the muscles only persists for a short time after death, and then disappears gradually.

If the muscles of a person supposed to be dead cannot be caused to contract when stimulated by the induction-coil current, life may be considered extinct ; on the other hand, if they retain the power of responding to this test, death, if it has occurred, must have been so recent that the inevitable changes have not yet had time to affect the muscles of the body. Certainly no person should be buried if his muscles are still normally contractile. The morbid fears of the public on the subject of the burial of persons not really dead could be completely allayed if this test were always applied before the certificate of death were signed.

Onimus and Legros* have shown that there is a stage in the dying of a muscle at which it gives the reaction of degenera-

* " Traité d'Électricité Médicale," Paris, 1888.

tion—that is to say, the irritability to the induction coil disappears first, while the response to direct battery current stimulation continues, giving rise to a sluggish contraction. This change sets in about four hours after death, and they relate a case in which the reaction enabled them to specify correctly the time at which death had occurred.

Marie and Cluzet,* who have recently repeated these experiments, have found that the muscular excitability disappears more or less quickly according to the nature of the disease which has caused death, and there may be differences in different individuals, but the reactions may begin to change after thirty minutes have elapsed since the time of death, and that a complete reaction of degeneration may make its appearance in one hour.

178. **Sensory Nerves.**—Just as the electrical stimulation of motor nerves causes muscular contractions, so the stimulation of sensory nerves produces sensations. Accordingly, when an ordinary mixed nerve trunk is stimulated its motor fibres set up contractions in the muscles supplied by it, and its sensory fibres convey to the brain of the patient experimented upon a peculiar sensation, strong or weak, in proportion as the current is strong or weak.

In the case of the direct current there is a sensation not only at closure and opening, but also during its steady passage, unless the current be very weak or of brief duration.

The sensations are largely if not entirely due to chemical effects, and generally are more perceptible at the kathode than at the anode, but depend in part upon the relative sizes of the electrodes. If one be much smaller than the other, then the greater density of current at the smaller one tends to increase the cutaneous sensations there. Much also depends upon the nature of the saline constituents with which the electrodes are moistened. With sodium carbonate solution the pain is greatest at the kathode where carbonic acid ions are entering. With sodium chloride it is the sodium ions entering at the anode which provoke the liveliest sensation. If the electrodes be held still in one place sensations of a burning character, accompanied by reddening, urticaria, or blistering of the surface, are caused by the accumulation of the chemical products. The current is less painful when the electrodes are firmly pressed upon the surface,

* *Arch. d'Élect. Médicale*, 1899, p. 543; 1900, p. 285.

because the contact is then better, and the current is distributed over more points of entrance.

A very complete account of the sensations and effects produced by the introduction of different ions by means of pads moistened with various solutions is given by Dr. Manuel Sanchez* in his essay on this interesting subject.

A single shock from an induction coil produces a sensation like that of a sudden make or break of a battery current, the severity of the shock depending upon the electromotive force and current in the circuit. An induction coil with its contact-breaker in action produces a series of shocks in which the individual impulses may be perceived, unless they follow one another too rapidly.

At fifty interruptions per second the sensations begin to become fused, and at higher rates of vibration the sensation feels more smooth or continuous than before. With rapid vibrations, one hundred per second and upwards, a benumbing effect becomes noticeable in the area of distribution of a cutaneous sensory nerve, if the electrode be applied to a point upon its trunk, this sensation of numbness being in addition to the effect felt in the place of contact of the electrode. With a small movement of the electrode away from the nerve-trunk the numb feeling may disappear. The numbness is a true anæsthesia, both tactile sensations and the perception of painful impressions being very greatly blunted, and a glow accompanied by perspiration often succeeds when the current is cut off.

When an electrode is moved over the surface of the skin systematically the position of the cutaneous nerves can often be exactly localized by using a very small electrode and a current which can just be felt, for whenever the electrode comes close over a sensory nerve trunk the sensation at once becomes quite strongly felt ; from this it appears that a nerve trunk is more sensitive to the stimulation than the nerve endings are. In testing muscles it is of advantage to know the position of these " sensory points," in order to avoid them and save the patient from unnecessary pain. On the dorsum of the foot there are several, which are apt to become painfully stimulated when testing the electrical reactions of the interosseal muscles. A little exploration of one's own cutaneous surface affords the

* " La Théorie des Ions en Électricité Médicale," Nantes, 1902.

best way of learning the position of these superficial nerve trunks.

Much fresh light has lately been thrown upon the sensory nervous system by the investigations of Dr. Henry Head.

In the Marshall Hall address to the Medico-Chirurgical Society in 1905, Dr. Henry Head, F.R.S., gave an account of certain investigations carried out by him in conjunction with Dr. W. H. Rivers and Mr. James Sherren. In the course of these studies he had an interesting experiment performed on his own arm. The cutaneous branch of the radial nerve was cut, and the process of return of sensation after the injury was carefully watched.

He found as a result of this experiment, confirmed by a large number of examinations of other peripheral nerve injuries, that ordinary touch sensibility included at least two types of perception. Recovery of sensation after complete division of a peripheral nerve begins with disappearance of the analgesia, and with the return of sensation to the extreme forms of temperature, but for a time the hand remains exactly as insensitive as before to the higher stimuli, such as light touch. The characteristics of a part which has again become sensitive to prick and to the extremes of heat and cold are: (1) The sensation radiates widely, is referred to remote parts, and cannot be accurately localized; (2) a prick produces a more unpleasant sensation than over normal parts; (3) the sensation produced gives no measure of the intensity of the stimulus by which it has been evoked. In order to distinguish this form of sensibility, Dr. Head has assigned to it the name "protopathic." With further recovery a second form of sensibility appears. This is associated with accurate localization of cutaneous stimuli and the discrimination of two compass points. With the return of this form of sensation light touch and intermediate degrees of heat and cold can be again appreciated. This form of sensibility should be called "epicritic."

Protopathic and epicritic sensibility probably depend each on a separate system of nerve fibres for the following reasons: (1) Occasionally, after division of a peripheral nerve, sensibility to pain, to ice, and to 50° C. may be abolished, but that to light touch and to water at 40° C. remains. (2) After complete division of a nerve protopathic sensibility returns before epicritic, whereas after functional division (incomplete destruction of the nerve) the two forms of sensation return *pari passu*. A part deprived of its nerve supply is liable to injuries, and the sores and ulcers

so produced heal slowly. Such sores heal rapidly and permanently as soon as protopathic sensibility has returned to the part, even though all epicritic sensation is still absent. A third form of sensibility was also detected. After the radial half of the arm and back of the hand had been rendered totally insensitive to cutaneous stimuli, these parts of the hand remained sensitive to pressure or to any stimulus that deformed the subcutaneous structures. The power of localizing such stimuli as could be appreciated was not lost. The fibres upon which this form of sensibility depended must therefore run with the motor nerves. This was called "deep sensibility." Every peripheral afferent nerve of the limbs probably contained protopathic and epicritic fibres. Towards the periphery the latter tended to fall into certain groups, and the area supplied by each group did not overlap that of another group materially. The protopathic fibres, on the contrary, overlapped to a considerable extent at the periphery of the limb. This overlapping became less as the posterior roots were approached, showing that these fibres still maintained to a certain extent their segmental arrangement. The threefold arrangement of deep, protopathic, and epicritic sensibility ceased in the central nervous system at the first cell junction. The impulses conducted along these three lines become sorted out into paths for light touch, for localization and stereognosis, for pain, for heat, and for cold.

Observations on the application of temperature stimuli to the intestine seemed to show that its sensibility resembled that which, in the skin, had been called protopathic. But it was entirely insensitive to all those stimuli which evoked epicritic sensation. Consequently, Head has suggested that the body within and without is supplied by afferent nerves which belong to the protopathic system. This can be divided into somatic and splanchnic, the latter including all that has previously been known as the afferent sympathetic.

The protopathic system is peculiarly associated with the reflexes and with feeling tone (pleasure and pain). The sensations evoked from it in answer to appropriate stimuli are widely diffused, and are not infrequently referred to parts at a distance. Its fibres regenerate with greater ease and rapidity than those of the epicritic system, or those of the motor nerves to voluntary muscle. This system retains to a considerable degree its original segmental arrangement.

The external surface of the body and limbs is innervated by a second system of fibres—the epicritic. This system is of later development, and regenerates more slowly than the protopathic. It is peculiarly associated with the localization and discrimination of cutaneous stimuli.

All subcutaneous structures are also innervated from afferent fibres that end in sense organs peculiarly susceptible to pressure. These fibres in the limbs and body wall run in conjunction with the motor nerves to voluntary muscles, and this "deep sensibility" is not materially diminished by the destruction of the sensory nerves to the skin (see Brain, Part 110, Summer, 1905).

A marked difference exists between protopathic and epicritic nerve fibres in their response to interrupted currents, for the former appear to be unaffected by impulses whose duration is less than about 0·002 of a second, and consequently current waves having that duration or less produce a stimulation which is more and more devoid of painful impressions as the duration of the impulses decreases, though they are still felt quite distinctly as a sensation through the agency of the epicritic fibres.

179. **Nerves of Special Sense.**—The nerves of special sense respond to electrical stimulation by their own special sensations; thus stimulation of the olfactory nerve is said to produce a smell "like phosphorus," stimulation of the auditory nerve gives rise to the perception of a sound, and stimulation of the optic nerve produces the impression of a flash of light. Some observers have even thought that the colour of the retinal effect seemed to depend upon the direction of the current, giving kathodal closure a reddish colour and anodal closure a bluish one. The retina may be stimulated with one pole at the nape of the neck, and the other over the closed eyelid. In making experiments on the eye, one may usefully bear in mind the accident which befel Duchenne, who apparently caused very serious damage to the vision of one of his patients when applying a strong current to his face. The effect may have been a retinal hæmorrhage due indirectly to the electrical application.

Duchenne remarked that the current of the secondary coil acts on the retina more strongly than that of the primary, and this is now known to be due to the longer duration of the waves in the former case. Waller* has also observed that longer stimuli are better adapted to the excitability of the retina, and shorter

* *Proceedings of the Royal Society*, July 27, 1899.

stimuli to the excitability of common sensory terminal organs. The optic nerve seems to behave like a protopathic nerve in this respect.

The auditory nerve also responds to stimulation by the battery current. To produce the electrical reactions of the auditory nerve fairly strong currents are required, and the associated effects upon the face and eyes and brain make the experiment unpleasant ; but the investigation is important, because of its bearing upon the treatment of tinnitus aurium.

The nerves of taste are also readily stimulated by electric currents.

180. **The Brain.** — In the case of the brain, experimental physiologists have made much use of electrical stimuli in determining the situation of motor centres in the exposed cerebral cortex. In ordinary electrical applications it is found that when a continuous current is passed transversely through the skull, with the electrodes on the temples or mastoid processes, there is a disturbance of equilibrium, producing a feeling of giddiness, or an actual unsteadiness, with a tendency to fall towards the side of the anode, and sometimes there is conjugate deviation of the eyes to the side of the kathode, with a kind of oscillation or lateral nystagmus.

It has been supposed that the disturbance of equilibrium depends upon a state of kathelectrotonus of one hemisphere, with anelectrotonus of the other ; the former hemisphere being in a state of exalted excitability, and the latter in a state of diminished excitability, their action is no longer balanced, and a sensation of giddiness is the result. The effect may be due to the influence of the current on the semicircular canals.

The brain is not influenced by induction-coil currents applied to the outside of the skull, and it has been said that they do not penetrate the skull. Certainly it is not possible to produce localised stimulation of the separate motor centres of the cortex by induction-coil applications to the skin over the Rolandic area.

The resistance of the bones of the skull has been put forward to explain this want of effect of coil currents on the motor cortex. Bone, however, conducts moderately well, though not so well as the soft tissues of the body, and it is quite easy to produce cerebral effects with direct currents, and no one has yet suggested that the ohmic resistance of bone is greater for interrupted currents than for direct currents. Some other explanation is

therefore necessary. Owing to the spherical shape of the skull, diffusion of current is favoured, and therefore the density of current is greatly lowered at a short distance away from the electrodes. For the same reason, the stimulation becomes evenly divided over the whole of the area between the electrodes, and the effects produced are likely to be effects of stimulating the brain as a whole rather than those of stimulating any small part of it.

Moreover, the scalp is very sensitive to induction-coil currents, and a painful effect is produced upon the skin in contact with the electrode when the actual current is still very small.

Battery currents produce effects upon the brain which can readily be perceived, and as they are generally unpleasant, it is advisable to use care when applying them for treatment. The precautions necessary are to avoid sudden makes and breaks of circuit, and to apply the electrodes in a symmetrical or median position, in order that the effects upon the two hemispheres shall be as far as possible balanced. If currents are carelessly applied, the patient will be disturbed by giddiness, by a tendency to faint, and by flashes of light produced through stimulation of the optic nerve. Nausea may be felt and nystagmus observed.

Professor Leduc of Nantes* has related the case of an elderly Judge who had been under his care at one time for facial paralysis. He was treated by direct current, and soon recovered from his paralysis, but afterwards continued to come at intervals for more treatment, because of the feeling of increased mental vigour which the galvanization of his head and neck afforded him. His words deserve quotation. He said: "I feel lighter, and my ideas are more clear. I can concentrate my attention more closely upon my work; I struggle more successfully against the sleep-producing effect of long pleadings; I grasp more clearly the arguments which are advanced before me, and I can weigh them more exactly; in fact, I find my intelligence is brighter and my work is more easy to do, and for that reason I come to you for an electrical application whenever I am confronted by a fatiguing or difficult piece of work."

Professor Leduc concludes that negative applications stimulate the functions of the brain, while positive have a calming and depressing action, and that negative applications afford a means —probably the best means—of relieving the effects of mental

* *Arch. d'Électricité Médicale*, May, 1899.

overwork, and of raising the intellectual powers to their highest level.

In the *Comptes Rendus* for 1902 Leduc published an account of some remarkable effects produced by rapidly interrupted currents passed longitudinally through the nerve centres.* The anode was placed on the hinder part of the back of a dog, and the kathode on the skull. The skin was previously shaved. The current was increased gradually, and at a certain strength general convulsions set in, the animal became unconscious, the sphincters were relaxed, and respiration ceased. When this stage was reached, the current could be reduced in part, and respiration then recommenced, and a state of tranquil sleep was induced, in which the animal remained until the current was stopped. During this period of sleep there was anæsthesia. As soon as the current ceases the animal jumps up and seems quite well, and no injurious results seem to follow. Later writers, in commenting upon Leduc's experiments, appear to regard the phenomena as due to the induction of an epileptic state by the electrical current.

181. **Other Organs.**—Besides the physiological action of electricity upon the nervous and muscular tissues, it has an action on secreting glands, upon the viscera, and, in fact, upon all living protoplasm. It is quite in accordance with what one would naturally expect, that a current passing through a secreting gland, or through its nerves, should cause increased secretory activity, and that a current passing through a viscus containing unstriped muscle should cause peristaltic contractions of that viscus ; and there is no need to enter into detail at present by describing the particular behaviour of the uterus, of the bladder, or of the intestine under electric stimulation.

182. **Death from Electric Shock.**—The fatal effect of powerful currents is due, in many cases, to stoppage of the action of the heart, which falls into a condition of irregular fibrillar twitching, from which it seems unable to recover, and quickly stops altogether. The tracings (Figs. 173, 174) show the results in some experiments upon cats under chloroform. In the first is seen the rapid fall of blood-pressure to zero after the passage of a current of half an ampère transversely through the thorax. A current of the same magnitude through the skull produced a trifling effect, with increase of blood-pressure, which is seen in

* "On the Induction of Sleep and Anæsthesia by Electrical Currents."

the first part of the same tracing. In the other figure is seen the secondary effect upon respiration, caused by the failure of the blood-supply in the respiratory centre. These tracings were taken during some experiments with the direct current. Oliver and Bolam have more recently published tracings showing that with alternating currents the results are similar. To cause death, the

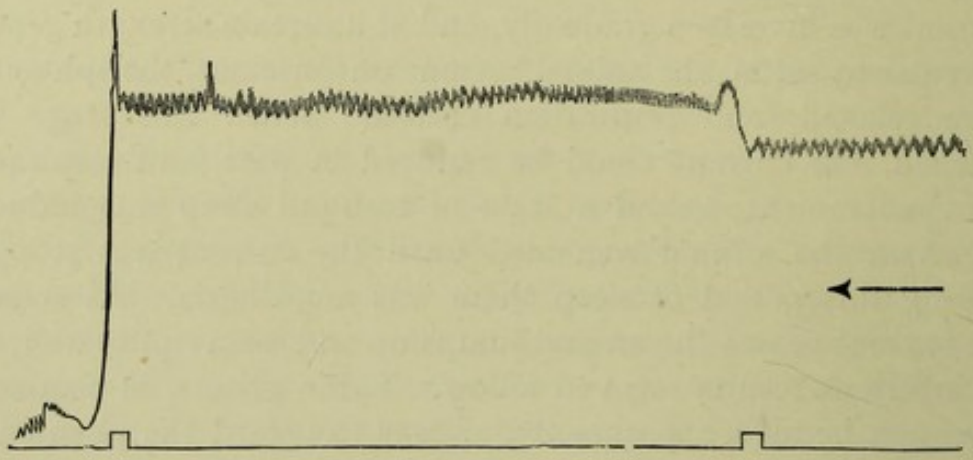


FIG. 173.—BLOOD-PRESSURE TRACING, SHOWING EFFECT OF ELECTRIC SHOCK THROUGH SKULL AND THROUGH THORAX OF A CAT.

currents must have a certain minimal value, and must traverse a vital organ, the heart being the most susceptible.

The most important researches upon the cause of death from electric currents are those made by MM. Prevost and Battelli,* and a valuable summary of their work will be found in the *Arch. d'Élect. Médicale*, 1902, p. 777, by Battelli. A very peculiar point is brought out in their researches—viz., that electric currents may kill in two distinct ways—that is to say, either by

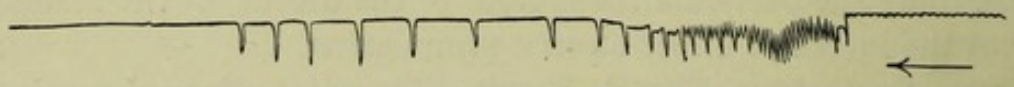


FIG. 174.—FAILURE OF RESPIRATION AFTER STOPPAGE OF THE HEART FROM ELECTRIC SHOCK.

a direct effect upon the heart, like that shown in the tracings just given, or by an entirely different effect upon the central nervous system, causing an arrest of respiration, the beating of the heart remaining unaffected. Battelli states that with low pressures (small currents) death occurs, in the first manner, through the heart. Among animals certain differences of susceptibility are observed. In dogs, for instance, the arrest of

* *Comptes Rendus*, March 27, 1899.

the heart's beat is final and proves fatal; in guinea-pigs and in rabbits the heart's beat is arrested and fibrillar twitchings are produced, but the natural beating may be resumed. In rats an arrest with fibrillar twitchings is produced, but lasts only so long as the current is passing, so that in these animals the heart recommences to beat in a normal manner as soon as the current is switched off, and they are not killed by stoppage of the heart. Strange to say, this effect of currents in arresting the heart is more evident with small than with large currents, and is not observed with very large currents, so that Professor Battelli even states that a heart arrested by an electric shock of small magnitude can be caused to recommence beating by a current of large magnitude sent through it afterwards. When the currents are large, it is the central nervous system which is the most affected; consequently, in cases of accident from contact with high-pressure conductors, and when large currents have traversed the patient's body, the heart-beat may not be arrested, but there may be a profound inhibition of the respiratory centre. As the arrest of respiration is not inevitably fatal, but may be recovered from either with or without the help of artificial respiration, it follows that beyond a certain point danger is decreased rather than increased with increase of current through the body. If this view is correct, it may account for some of the sensational non-fatal accidents which have happened of late years with very high-tension currents.

The views of D'Arsonval that electric shocks prove fatal by arrest of respiration are thus seen to be correct in certain cases only. It is probable that the fatal accidents are generally cases in which the heart has been arrested, while the severe but non-fatal cases have suffered through shock to the nerve centres, with temporary arrest of respiration, but their hearts have escaped.

In the absence of direct observations, the minimum fatal current for human beings may be estimated at about one-half to one ampère. The most common path of the discharge is from one conductor to earth through the body, but the current may also pass directly from the body to the other conductor of the system. In the first case the point of exit is generally by the feet. Burns of the skin should always be looked for at the points of entry and of exit; they may be severe or slight. When the current goes to earth through the feet, these may not show signs

of burning if the foot covering is damp. The severity of the burns is proportional to the duration of the discharge. Most of the fatal accidents have been with potentials above one thousand volts, but a number of cases are on record of death from contact with circuits of 200 or even of 110 volts.

Experience has shown that the body may carry a current sufficient to produce extensive burning at the points of contact, without causing death, and this may be the case even when the current has fairly traversed the trunk. In a recent accident in London two men were concerned, and the current passed from the live conductor to the first man, and from him through the second to earth. The first man survived, though the second was killed. The relative danger of alternating and direct currents is not decided; there is probably no great difference. Batelli considers that there is diminution of danger with increase of frequency when alternating currents are concerned. (See also § 107.)

CHAPTER X

GENERAL THERAPEUTIC CONSIDERATIONS

The effects of electrical currents—General electrization—Methods of general electrization—Electrolysis—Ionic medication—Effects of static applications—Effects of high-frequency currents—Effects of X-rays—X-ray dermatitis—Effects of radium—Phototherapy.

183. **The Effects of Electrical Currents.**—In the application of electrical currents to medical treatment certain methods must be followed in order to obtain the effects desired. The kind of current to be employed, its proper strength, and the duration of the applications, must also be considered.

A large part of the benefits derived from electrical applications can be ranged under the heading of stimulation, and by virtue of the stimulating effect which is produced by a general application of electricity to the whole body one is enabled to obtain good results in the treatment of many general morbid conditions.

Electrical treatment has long been dominated by the idea that its chief utility lay in the treatment of nervous disorders, and that local applications to paralyzed parts formed the only kind of electrical treatment worth following. This is by no means the case, and of late years the advantages of general electrization of the whole body for general disorders has received more attention.

The electrolytic transport of ions and its possible employment for medical purposes in the percutaneous administration of drugs has acquired fresh interest of late years. The effects of static and high-frequency applications also require examination, and the therapeutic effects of X-rays and radium and of electric light for phototherapy are also new and of great importance.

184. **General Stimulation and Trophic Effects.**—For purposes of simple stimulation the best form of electrical application is the variable current, and this is generally obtained from the

induction coil, from the sinusoidal current, or from a direct current source with the aid of some form of rhythmic or other interrupter.

D'Arsonval, who examined the trophic effects of electrical applications of various kinds, has shown that induction-coil currents, by producing more or less extensive muscular contractions, augment the oxidation processes of the body, but that even when so gentle as to cause no muscular contraction they can nevertheless cause modifications in the nutritive exchanges of the body, with increased production of heat ; moreover, that the sinusoidal current produces a more marked effect. By its use the respiratory exchanges can be augmented by 25 per cent., and that without provoking any muscular contractions whatever. This result is found both in men and in animals.

The direct current, on the other hand, in spite of the general belief in its trophic effects, has given negative results, both in experiments on man and upon animals, so far as an effect upon respiratory exchanges is concerned.

Experiments were made by Dr. Beard* to determine the effect of "general faradization" upon the growth of young dogs, and they were kept under treatment for four weeks, being treated daily with an induction-coil current ; at the end of the time the two animals which had been so treated had gained in weight faster and were perceptibly bigger than two others which had been kept untreated as control animals.

Debedat† made a series of experiments on the muscles of young rabbits with the various kinds of electric applications used in medical treatment. The group of hamstring muscles was chosen ; those of the left side were stimulated in various ways daily during twenty days, for four minutes a day ; those of the right side were left for purposes of comparison. At the end of the period the animals were killed, and the muscles of the two sides carefully removed and weighed ; portions were also hardened and examined microscopically. The modes of stimulation were as follows : (1) The induction-coil current with rhythmic periods lasting for one second, and followed by one second of interval, and so on for four minutes ; (2) the battery current of two milliampères, with the same periods of stimulation and repose ; (3) electrostatic sparks, two or three milli-

* Beard and Rockwell, "Medical and Surgical Uses of Electricity."

† *Arch. d'Électricité Médicale*, February and March, 1894.

metres long, repeated every two seconds; (4) tetanization of muscles for four minutes, by means of an induction coil without any intervals of repose; (5) steady battery current for four minutes, without intervals of repose.

The results showed a gain of 40 per cent. in weight on the stimulated side with the rhythmic induction shocks, and of 18 per cent. with the rhythmic battery current. The prolonged tetanization caused a marked loss of weight; the prolonged steady battery current caused a slight increase in weight, and adhesions had been formed between the skin and the muscle, at the points of application of the electrodes. The gain in weight was due to a true growth of the muscle; the loss was accompanied by histological evidence of damage to the muscle fibres. The static sparks had no effect. The author concludes that for promoting the growth of muscle by electricity the current should be interrupted, and the periods of contraction and repose of the muscle should be arranged so as to approximate to the conditions of a muscle during the performance of rhythmic gymnastic movements, with about thirty periods of contraction and thirty intervals of rest per minute, prolonged tetanization being hurtful.

H. Bordier* has made experiments of the same kind on a healthy human being, and has shown a direct result upon the growth of muscle from electrical stimulation. He made use of the combined "galvano-faradic" current interrupted rhythmically 30 times a minute, with intervals of one second. The biceps, brachialis anticus, supinator longus, and the extensors of the wrist of one side, were stimulated on alternate days for periods of ten minutes. After two months the parts were measured, and compared with measurements which had been carefully taken before treatment was begun. The increases were as follows: Girth at centre of arm, 2·7 centimetres; at lower third, 2·3 centimetres; of forearm, 2 centimetres below fold of elbow, 2·3 centimetres gain; at 5 centimetres lower down, 2 centimetres gain.

185. **General Electrization.**—By virtue of the stimulating effect which is produced by a general application of electricity to the whole body, one is enabled to obtain good results in the treatment of many morbid conditions.

The advantages of general electrization in disorders of nutri-

* *Arch. d'Électricité Médicale*, 1902, p. 331 (with illustration).

tion have been repeatedly insisted on, particularly by D'Arsonval and those who have followed his teachings. The group of general diseases which are characterized by defective or perverted nutrition includes not only simple anæmia, chlorosis, debility, and neurasthenia, but also rickets, gout, rheumatism, rheumatoid arthritis, diabetes, obesity, etc.

The influence exercised by general electrization in states of defective nutrition and in convalescence may be presumed to involve two separate factors, the first being a stimulation of the activity of nutritive exchanges, leading to a growth or renewal of the tissues, while another, which may be equally important, is the stimulation given to processes of elimination of waste products or toxic substances from the system.

The results of general electrization are mainly tonic in their nature; a feeling of vigour follows, depression or fatigue are relieved, the appetite is increased, the patient sleeps more soundly, there is an increase in the firmness of the muscles and an improvement in the circulation. In some patients these results follow promptly, in others their development is more gradual.

The old plan of treating patients with the currents of a coil or a magneto-machine by means of metallic electrodes placed in the two hands may be regarded as a rude attempt at general electrization.

Drs. Beard and Rockwell have described a process of "general faradization" by placing one pole of the induction coil under the feet or the gluteal region, while the other is moved over the general body surface, with the patient standing or sitting upon a large metal electrode covered with moist flannel, and kept warm by means of a hot-water bottle. The active electrode is moved over the various parts of the body, two or three minutes being given to the head, neck, back, abdomen, and the limbs in order.

The strength of current should be so regulated that the sensations felt by the patient should be of the nature of a pleasant thrill, without any pain or discomfort.

186. **Central Galvanization.**—This is a plan of applying continuous currents to the nerve centres, also introduced by Drs. Beard and Rockwell as a means of general electrization. It consists "in placing the negative pole at the epigastrium, while the positive pole is applied to certain parts of the head (chiefly

the vertex and forehead), to the sympathetic and pneumogastric in the neck, and down the whole length of the spine from the first to the last vertebra." It is said to be useful in cases of hysteria, neurasthenia, sleeplessness, dyspepsia, and other complaints. The duration of each application may be for ten minutes, the strength of current ranging between five and ten milliampères. according to the part under treatment, and being reduced a little for the applications to the head.

Dr. Armstrong* of Buxton advises currents of one to five milliampères for the head, and up to twenty milliampères for the spine, with sittings of ten to thirty minutes repeated three or four times a week, or daily. He quotes cases in which he obtained good results in palpitation and irregular action of the heart, in conditions of cerebral exhaustion, and in neurasthenia. With currents of too great strength, or too abruptly made and broken, unpleasant effects may follow, especially in the applications to the brain.

Electrical applications to the nerve centres will probably be found useful in many cases of the kinds just mentioned. Capriati's experiments (§ 190) with healthy individuals have shown that the application of currents of ten to fifteen milliampères to the spine for ten minutes produces a marked effect upon the muscular power.† This favourable effect is commonly observed with patients under treatment.

187 **Galvano-faradization.**—The simultaneous use of the continuous and the interrupted currents has been recommended. The method consists in connecting together the secondary circuit of an induction coil and a direct-current battery by joining up the negative pole of the one with the positive of the other, so as to send both currents together through the body. It is thought that "the effects of the interrupted current are enhanced by a simultaneous galvanization." Dr. de Watteville had a very high opinion of the advantage of this mode of treatment, particularly for electrization of the abdominal viscera, in rheumatic conditions, and in atrophic paralysis. The method is still occasionally used.

The strength of each component may be about the same as when either is being used alone.

* *Transactions of the Royal Medical Society of London*, vol. xxi.

† "Influence de l'électricité sur la force musculaire," *Arch. d'Électricité Médicale*, November, 1899.

188. **The Electric Bath.**—The method of general electrization to be preferred is that of treatment by the electric bath with sinusoidal current. The other modes of applying electricity to the general system have similar effects, but are most probably of less general utility. They include the general applications of high-frequency currents and of statical treatment, as well as the methods of " general faradization " and " central galvanization " already referred to.

The apparatus used for the electric bath has been described in § 71. For the administration of the bath the procedure should be as follows : The current should be turned on to half strength before the patient enters the bath, and the circuits tested, the strength of the current being gauged by feeling it with the hands immersed at the two ends of the bath.

The patient, after entering the bath, should sit up for a minute or so to become accustomed to the sensations produced by the current, and this should be increased slowly and cautiously, and the galvanometer watched.

With the sinusoidal current 30 or 40 milliampères are generally sufficient. With induction-coil currents the strength should not be so great as to make the patient's muscles rigid. A metronome or other rhythmic interrupter (§ 65) is a very useful adjunct ; when one is employed the currents should be less strong.

After the bath the patient shall dress slowly, in order to allow the activity of the circulation in the skin to diminish during the process of dressing. If the patient dresses hurriedly while the skin is perspiring, he will feel damp and uncomfortable, and will run the risk of taking a chill. With due care there is very little danger of cold after an electric bath.

The duration of the bath should be for ten or fifteen minutes, and they may be given on alternate days. Twelve baths should produce signs of a good result if the treatment is going to prove useful, but in many chronic states more than this number will be wanted.

It is usual for patients to feel a little inclined to sleep some hours after a bath, and it is as well to tell them of this beforehand, or they may take it as an unfavourable sign.

In all electric bath treatment the utmost care must be taken with the conducting circuits and the regulating apparatus. Any defects at the connections, at the binding-screws, or elsewhere, must be guarded against. The patient in the water is helpless,

and easily becomes alarmed at the occurrence of anything unexpected in the way of sudden changes in the flow of current, and he may consider it to be dangerous to come for any more treatment if he has once received a disagreeable shock. On this account it is recommended always to make a trial of the entire bath circuit at the last moment and to have the current flowing before the patient steps into the water. When the patient is already in the bath, there should be no hitch.

Of late years electrical applications have come into very general use in spas and health resorts, not only abroad, but also in this country, and this speaks volumes for the superior advantages of electricity over hydrotherapy pure and simple. Electro-therapeutics also find a more favourable public at such places than they do in large and busy towns, for patients who cannot spare the time for a regular course of treatment when at home are able and willing to do so when staying at a health resort, and detached from their daily business.

189. **Electrolytic Effects of Direct Currents.**—Perhaps the most striking effect of direct currents is their electrolytic action. Electrolysis is used in surgery as a means for producing destruction of tissue in a simple and minutely localized manner. This is effected indirectly by the action of the chemical bodies liberated at the poles during the passage of the current. As these bodies are different at the two poles, so the actions which take place at the poles differ from one another to a certain extent. The advantages of being able to localize the effects so precisely is well seen in the operation for the removal of hairs, for here the destructive effects are confined to such a minute area in the immediate neighbourhood of the hair follicle that no perceptible scar is produced, although the hair follicle is eradicated. Electrolysis has been used for the following purposes: (1) The removal of superfluous hair, of moles, and of warts; (2) destruction of nævi; (3) coagulation of blood in aneurysms; (4) destruction of strictures in the urethra, lachrymal canals, œsophagus, rectum, and Eustachian tube. Electrolysis has also been used for the destruction of cancerous growths and for the treatment of fibromyoma of the uterus.

The use of electrolysis for the introduction of ions of active drugs into diseased areas of the body has only recently attracted serious attention. Its importance is well emphasized in a

paper by S. Leduc,* from which the following paragraphs are taken.

After considering examples of the electrolytic introduction of powerful drugs in sufficient amount to produce general systemic effects, he goes on to say :

" The local effects of ions are a good deal more interesting than the general ones. To my mind, these local effects are of such importance that I believe the time will come when we shall consider many of our present procedures of drug-giving to be absurd. I mean those procedures in which we desire to act upon one portion of the body only, and yet are compelled to fill the whole of the body with some drug given by the mouth for the sake of its local action, although the effect which it exercises upon the body at large may be undesirable or even injurious. It has been shown by Professor Bouchard that it would be a rational procedure to replace general treatment of this kind by local treatment whenever local treatment can be managed. The electrolytic transport of ions manifestly supplies us with new methods of obtaining this object. By its means we can introduce any one of a series of ions into the protoplasm of the actual cell, in spite of its power of resisting the entry of foreign material, and we can be sure of obtaining from each ion its own special action at the place where we introduce it.

" When we reflect upon the variety of ions, and consider the depth to which we can make them penetrate, we can see how ineffective it is to be content with applications of ointments or of liniments to the mere surface of the body as a means of producing topical effects. Such things act only in a superficial manner, and the amount which actually penetrates into the tissues is only a minute fraction of the quantity applied to the surface. It is true that absorption does take place, but this occurs chiefly with highly diffusible compounds, which pass quickly into the general circulation, and are carried quickly away from the seat of their introduction.

" Many valuable drugs penetrate either with great difficulty or not at all, when applied in the old-fashioned way, but electrolysis introduces them with ease to any required depth. If the hair is shaved off from two areas of the skin of a rabbit, and a pair of electrodes imbibed with a solution of bichromate of

* " Les ions en Médecine," *Arch. d'Électricité Médicale*, September 25, 1904.

potash be applied, and a current be passed between these electrodes with a density of two milliampères per square centimetre for 40 minutes, the following results will follow : At the anode the ion which penetrates is that of potassium, and it produces no appreciable change, either immediate or remote, while at the cathode, where the chromic radical has penetrated, the skin is turned red and a zone of congestion is produced, and this is duly followed by the development of a superficial slough, which clears off in the course of about three weeks, leaving behind it a new formation of skin or of scar tissue, according to the duration of the original application.

" When the electrodes are moistened by simple acid solutions which are not concentrated, the effect upon the skin at the anode is that which is due to the introduction of the ion of hydrogen, and the effect for all ordinary acids is identical. With dilute alkaline solutions we introduce the ion OH at the kathode, and the effect in this case is as definite and precise as in the former one. In each case the sore produced by a long or strong application has its own peculiar characteristics. The ions of potash or soda or magnesia do not produce any very definite effects except when introduced in large amount. The ions of the metals of the alkaline earths, on the other hand, produce, if given in sufficiently strong doses, a characteristic destruction of the surface of the tissue. Dogs on whom I have experimented with solutions of calcium chloride were able to endure a density of current of 15 milliampères per centimetre for thirty minutes without discomfort. The surface at the anode then seemed white, as though impregnated with calcium carbonate, sulphate, or phosphate. Subsequently, inflammation and œdematous swelling set in, and this changed into an ulcer with an indurated base and undermined edges, which gradually healed, preserving its character of induration for more than a month. Barium and strontium compounds act in the same manner.

" Of all the ions with which I have experimented, the one whose introduction appears to be the most painful is the ion of carbonic acid ; this is an ion which exists in large amounts in the tissues of the body. I have found it very difficult to study its effects on account of the pain caused by attempts to introduce it. The ion of sulphuric acid has the special effect of producing a smooth, hard dryness of the surface which is readily recognised.

"Of the heavy metals, there are many whose ions are more or less caustic, probably because they coagulate albuminous substances, but the one which is of most interest from a medical point of view is the ion of zinc. This ion is an antiseptic of the first rank, and when applied electrically, it can be made to penetrate the tissues of the skin to any desired depth. There is no wound or ulcer which cannot be disinfected by its employment, provided its surface can be reached by the electrodes. One of its peculiarities is that it provokes but little inflammatory reaction. When I have experimented with zinc upon the skin of animals, and have caused superficial or even deep ulceration, I have observed that the wounds produced show no inflammatory effect or sign of infection from germs, even if they are left completely uncovered; on the contrary, they remain aseptic, so that it appears as if the ions of zinc which they contain serve as the best possible of antiseptic agents. Although I have examined the ions of many other metals, I have found none other so interesting or so valuable in this respect as those of zinc. Zinc ions should be used in the treatment of chronic ulcers, sinuses, or fistulæ, the method being far preferable to curettage, which manifestly incurs risks of setting free infective agents, and of admitting them into the blood and lymph channels of the part operated on.

"Some of the more complex ions of organic compounds can also be made use of in electrolytic applications, as, for instance, adrenaline, cocaine, and others. With cocaine anæsthesia of the surface can be produced in five minutes with a current of small density, but its practical employment in this way requires discrimination, because irritation of the skin is apt to follow, with a brown discoloration, which may persist for a considerable time. It is interesting to note that cocaine introduced in this way diffuses away very slowly from the point where it is introduced.

"Salicylic acid is another body whose ions seem well tolerated by the tissues. Very little local inconvenience follows its introduction. I have used it successfully in the treatment of dry pleurisy. A large pad soaked in a two per cent. solution is applied to the whole of the affected region, and a current of 100 milliampères is caused to flow for half an hour. After the application the skin has a uniformly red appearance, but in almost every case in which I have tried this remedy the pain and the short-

ness of breath have disappeared, and the patients have declared themselves more benefited than by any other kind of application.

"Other writers have demonstrated the good effect of the salicylic ions in cases of chronic rheumatism.

"Chlorine ions seem to have a marked effect in producing resolution of scar formations and stiffened tissues. By means of them stiff joints can often be rapidly cured without the need for painful wrenching movements, and under the electrolytic treatment one can see the stiffness disappear gradually from day to day, and the affected joints recover their original power of movement. This result has been noted by myself on many occasions. It is of primary importance that the disease which originally produced the stiffness shall have disappeared, and that no active inflammatory process be going on at the time of the treatment. The best procedure for obtaining this softening of scar tissue is to use a one per cent. solution of common salt as the electrolyte, and to apply the cathode to the affected region under this pole. The tissues receive chlorine ions and part with the ions of sodium, and these exchanges seem to modify the chemical constitution of the tissues in the way best adapted for the softening of adhesions and cicatricial tissue. I can quote a case where a stiff wrist of six months' standing, the result of phlegmonous inflammation, had resisted many kinds of treatment, including forcible movements under an anæsthetic, but recovered free movement after two applications of the electric current. Cases of stiff knee have also, in many cases, become quite free after a few applications of this method. The more accessible a joint is, the more easily the results are obtained, and for this reason greater difficulty is found in the treatment of ankylosis of the hip or the shoulder joints than of such joints as the knee, the wrist, or the ankle, which are less covered by layers of the soft tissues."

190. **"The Refreshing Action" of the Galvanic Current.**—A peculiar effect of direct currents, which may be due to the transport of ions, was investigated by Dr. Vivian Poore,* who made some remarkable experiments upon the refreshing action of the continuous current on the fatigue of muscles, produced when a weight is held out steadily at arm's length. In one instance a patient, after holding out his arm horizontally for a

* "Electricity in Medicine and Surgery," Dr. G. V. Poore, London, 1876.

period of four minutes, with a weight of seventeen ounces in the palm, felt great pain and fatigue in the muscles, and declared his inability to go on, but was relieved at once by the passage of a constant current in a descending direction along the arm. Another person, experimented on in the same way, felt pain and fatigue after holding out the weight at arm's length for seventy seconds, but the application of the current at once removed both, and he continued to support the weight for five minutes and a quarter, and at the end of that time was still able and willing to go on. Dr. Poore tried similar experiments on several of his friends, and they all tend to show that the endurance of voluntary muscular action is very greatly increased by the passage of a constant current, which also mitigated or abolished the fatigue felt during or after the effort.

Dr. Poore also demonstrated that the force as well as the endurance of a muscular effort could be increased by a galvanic current. Eight successive squeezes with a dynamometer, at intervals of ten seconds, gave an average of 48½ pounds for each squeeze, but eight more squeezes, with the aid of the current, gave an average of 59½ pounds, although they came ten minutes after the first series, and while there was distinct consciousness of fatigue from the first experiment.

The current used was never strong enough to produce involuntary contraction of the muscles.

Capriati has more recently examined this matter with the aid of scientific methods of measurement. He has found that the direct current applied along the spine increases the muscular force of an individual, and that such increase persists for one or more days afterwards. Similar results followed applications of direct current to the limb tested, but were less marked; and finally they may also be observed after electrification by static charging. The direction of the current, or the polarity of the charging, appear to have had little or no importance. The magnitude of current used in the first experiments on the spine was 10 to 15 milliampères.

191. **Inhibition of Strychnine-Poisoning by Currents.**—Another peculiar effect of the current upon the symptoms of strychnine-poisoning has been described by Charpentier and Guilloz.* They have stated that the passage of a direct current arrests the manifestations of poisoning by the alkaloid in frogs and in guinea-

* *Arch. d'Électricité Médicale*, 1904, p. 69.

pigs. So long as the current flows there is quiescence, although the stoppage of the current is quickly followed by the development of the characteristic tetanic spasms. By means of prolonged electrical applications death from strychnine may be prevented if the animal is kept quiet until the poison can be eliminated by the kidneys.

192. **Effects of Static Applications.**—The effect of a static charging is to increase the frequency of the pulse and its regularity. The blood-pressure is raised, and this was observed as long ago as 1748, when Jallabert noticed in a certain case an acceleration of the pulse from 80 to 94, and saw a phlebotomy wound which had ceased to bleed recommence after a few minutes of Franklinization, and give a stronger jet than before; the action of the skin is increased, and nutritive exchanges are accelerated. The effect on the nervous system is sedative, patients sleep better, and they may even show a tendency to fall asleep during the process of treatment.

Capriati, experimenting upon tadpoles with static charging, found that they developed more energetically and rapidly than the control individuals. And Picciano, who watched the development of silkworms under different forms of electricity, found that the product of those subjected to Franklinization was superior to that of silkworms which had developed under ordinary conditions.

Truchot* made some experiments upon himself, in which he was charged fifteen minutes once or twice daily for a week, but it is not specified whether the charging was positive or negative.

The pulse was increased in frequency after each application, being raised from 65 to 80, but apart from this immediate effect there was also a gradual rise in the average daily rate, so that after the fifth or sixth charging the pulse remained at 80 for the whole day, and only began to return to its normal frequency two days after treatment had been discontinued, finally reaching its normal rate of 65 per minute after the lapse of a week. The temperature also showed a gradual rise, being 97·9 at the beginning of the treatment and 99·3 at the end of the week, returning slowly to its former level during the next few days.

The strength of grasp was augmented by each charging, rising from 42 to 44 kilogrammes after the first time, from 41 to 43 after the fourth, and from 40 to 42 after the sixth; but these

* *Archives d'Électricité Médicale*, February, 1894.

figures show that there was a progressive decrease in the muscular power during the treatment, and that this was gradually restored when charging had been discontinued.

Truchot considered that at first metabolism was increased and internal oxidation improved, but that afterwards there was increased tissue waste with less perfect oxidation. His general condition showed increased appetite for the first day or two, but later there was a diminution; sleep was disturbed, and a feeling of languor and feverishness showed itself.

D'Arsonval found a slight increase of the respiratory exchanges under the influence of static treatment. Other writers have stated that the thermogenesis of the human body increases sensibly during and for some time after each Franklinization.

In practical treatment it is noticed that some patients, particularly such as are weak and anæmic, experience a marked feeling of improvement as soon as the charging begins; while others, especially gouty and plethoric individuals, remain indifferent, or may even show by their words or movements that they find it uncomfortable. It is probable that this is due to the effect on blood-pressure. Those whose pressure is low feel better as soon as it is raised, while those whose blood-pressure is already high are made uncomfortable by the treatment.

Many writers report favourably on the value of static treatment in neurasthenia, and in the treatment of insomnia and mental fatigue; and in certain forms of insanity and morbid mental states favourable results have followed statical applications. In the nervous disturbances which occur about the time of the menopause decided benefit may be obtained from simple static charging with the use of the negative breeze.

Statical applications undoubtedly act upon the function of menstruation. With patients receiving a course of treatment for conditions quite unconnected with the generative functions it is common to remark some effect upon the menstrual periods. Professor Doumer,* of Lille, has published his notes on 400 women treated by static electricity. In 342 the uterine functions were quite normal; in the rest, 58 in number, there was some complaint of menstrual trouble, mainly of the nature of dysmenorrhœa. Among these patients there was a hastening of the commencement of the period in 68 per cent., and an increase of the flow in 77 per cent. Among the 400 cases there were 178

* *Archives d'Électricité Médicale*, 1897, p. 96.

who had some pains or discomfort about the date of the commencement of their periods, and 73 per cent. of these, 130 persons, were relieved of these symptoms, while the remainder were not. Menstrual irregularity was present in 51 cases, and quickly disappeared in 31. These results followed for the most part upon simple electrostatic charging, but the breeze or the roller applied to the lumbar region produced a more prompt result. These effects may have been due to the general influence upon blood-pressure, which seems to be the most important effect hitherto observed in connection with static applications.

When the brush discharge is used, the action probably depends upon the peculiar stimulation of the sensory nerves of the skin which is produced. With the point electrodes these sensory impressions can be made to vary from a cool and gentle breeze effect to an intensely pungent pricking, and much of the success of static applications depends upon the adjustment of the degree of cutaneous stimulation to the nature of the individual case.

The effect of brush discharges upon pain in the superficial cutaneous nerves, as, for example, in headache or neuralgia, is sometimes very striking. Care must be taken when treating patients for the relief of pain not to spoil the effect by accidental sparks or shocks. With the negative point (the patient charged positively) there is not so much risk of this, for sparking does not occur under these conditions, except with the point at very close quarters.

The effect upon the skin of a strong brush discharge through woollen clothing remains plainly visible for some hours afterwards, in a persistent reddening or in the form of urticarial elevations.

The most intense cutaneous stimulation is that produced by the roller electrode; and the severity of this mode of application demands that it shall be used only for brief periods of a few seconds at a time. The shock which is produced by the application of a spark from the knob or ball electrode relieves pains of a myalgic nature, and often relieves them instantaneously. Probably it acts by a sort of forcible wrenching of muscle fibres. Often it is useful to request a patient with a pain in a muscle to assume the attitude which provokes or increases the muscular pain, and then to apply the spark or sparks to the painful part. In lumbago this treatment by sparks sometimes relieves promptly.

The muscular contraction produced by applying a spark to a muscle has been used in diagnosis, and it is said to have certain advantages in muscle-testing.

The local action of static discharges upon the skin is shown by its effects in certain skin diseases. It has been frequently noticed by others, and it has also come under my own observation, that repeated applications of the brush discharge to the scalp seem to stimulate the growth of the hair. In pruritus, which is so often intractable to many forms of treatment, in psoriasis, in eczema, and in varicose ulcers of the leg, the brush discharge is often efficacious.

Albert Weil has reported a case of lupus of the thigh cured by the brush discharge and static sparks.*

193. **Effects of High-frequency Currents.**—High-frequency currents provide a method of general electrisation somewhat similar to that obtained with the statical machine or with the electric bath. Each of these methods has its special advocates, but the selection of one or other for use will depend a good deal upon the resources of the individual medical man. Thus, one will have special conveniences for an electric bath, another will find a static machine more suitable, and so on. Good work can be done by all the modes of general electrisation, and the high-frequency methods of D'Arsonval have not as yet been shown to possess any conspicuous advantages over the others. The physiological effects upon which their medical applications are based are the very marked increase of metabolic activity which has been observed in experiments with high-frequency currents upon animals and upon men ; thus, D'Arsonval reports the output of CO_2 in the case of a human being as being raised from 17 litres to 37 litres per hour. Associated with this there is a considerable increase in the production of heat—namely, from 79 calories to 127 calories per hour—the body temperature remaining steady at a normal point.

Other physiological effects which have been noted are a superficial analgesia or anæsthesia of the skin in contact with the electrodes, and a decrease of excitability of the nerves and muscles in the neighbourhood ; there is a tendency to relaxation of the peripheral vessels, the blood-pressure is lowered, the surface temperature is raised, and the amount of nitrogen and of phosphoric acid excreted in the urine is also increased.

* *Progrès Médicale*, 1900.

The increase in the surface temperature causes a general sensation of stimulation on the part of the patients submitted to high-frequency treatment. A feeling of warmth, and even an actual perspiration, is not uncommonly observed. The effects of auto-conduction, of auto-condensation, and of direct (bipolar) applications, are somewhat similar.

There is no doubt that high-frequency treatment exercises an influence upon the course of a certain number of morbid states, although in many of these its influence for good is not of any particular degree of excellence.

In gout, rheumatism, diabetes, and obesity it has been extensively tried, but hitherto the results obtained have hardly justified anticipations. In diabetes, for instance, although numerous cases have been published in which a diminution of sugar has been observed, its complete disappearance is very rarely noted, and the patients generally remain diabetic throughout. Decrease of the daily sugar in diabetes can be produced by various forms of electrical application, notably by the electric bath with sinusoidal current, but the cure of diabetes is quite another matter, and, so far, it cannot be accomplished with any certainty by electrical methods of treatment, although a few apparently successful cases have been recorded.

In gout it appears that the high-frequency treatment may precipitate an acute attack. In acute rheumatism it is considered by certain experimenters to be contraindicated. In chronic rheumatism good results have been known to follow, but only after numerous applications.

In neuralgic pains, and in neuritic affections with pain—as, for example, in sciatica—some encouraging results have been obtained. In other affections of the nervous system high frequency has not yet accomplished much.

The most promising direction for work on the general effect upon the body of high-frequency currents is that of their influence in reducing the blood-pressure of persons suffering from arterial hypertension, for it seems fairly well established that high-frequency currents afford a means of keeping the arterial tension at its normal value, and of opposing arteriosclerosis and its complication, cerebral hæmorrhage. In many such cases Moutier has observed notable lowering of the arterial tension, and a permanent influence upon the condition of the walls of the arteries with diminished vaso-constriction.

The spark from a metallic electrode is of value in angioma and in tubercular lupus. For flat angiomata (port-wine mark) Bergonié applies an aigrette of very numerous small sparks; the tissue becomes pale after a few seconds of this application. This is followed by an inflammatory reaction, which results in a cure of the subcutaneous condition, with more or less decolourization of the epidermis. Strebel of Munich finds that active sparks may cure lupus and rodent ulcer. His application is by a pointed metallic electrode from the Oudin resonator, held at a distance of 1 or 2 millimetres from the surface; a stream of sparks is allowed to pass uninterruptedly. After about five seconds the skin blanches, the epidermis is shrivelled or fissured, and the blood-vessels are all constricted. The spark is allowed to act for ten or twenty seconds. An inflammatory reaction is produced, and this is succeeded by elimination of the morbid tissues and a slightly depressed cicatrix, at first red, but which soon becomes indistinguishable from the sound skin. Small moles and warts may be destroyed in a similar way.

The local application of high-frequency discharges to cutaneous disorders is sometimes made with a metallic point electrode, or with the glass vacuum electrodes (Fig. 144), or with the effleuve from points held just beyond sparking distance.

The morbid conditions of the skin in which success has been most commonly obtained with high-frequency treatment are psoriasis, eczema, acne, sycosis, and lupus. The action seems to be one of stimulation or counter-irritation, and perhaps the generation of heat and the production of ozone and of oxides of nitrogen at the actual skin surface may play a not unimportant part in bringing about a favourable result.

There is no doubt that high-frequency applications have an effect upon lupus, and the action of static brush discharges upon lupus, already mentioned, may be borne in mind in this connection. Several writers have published cases which appear quite satisfactory. Chisholm Williams has reported that twenty applications of five minutes each, extended over ten weeks, suffice to clear up any non-ulcerated small patch of lupus. The effleuve, the high-vacuum glass electrode emitting X-rays, or an ordinary glass electrode, may be used.

A group of conditions for which high frequency has also been found useful is that of piles, rectal fissure, and pruritus ani. These are treated by emans of a special electrode, consisting of a

stem carrying a cone-shaped extremity of bare metal. Doumer has reported twenty-six cases of piles which were all more or less successfully treated. He finds that the benefit is most marked in recent and acute cases, and least so when there were considerable structural changes in the parts.

Chisholm Williams,* Oudin, Doumer, Rivière, and others, have reported favourably upon the effect of high-frequency in pulmonary tuberculosis, and have published cases. Further investigations into the question are certainly desirable.

In this connection it is interesting to note an extended series of experiments on guinea-pigs conducted by Drs. Lagriffoul and Denoyés, and recorded by Dr. Denoyés in his book. He there insists that the treated animals were less affected by the inoculations than those left untreated. Otherwise the results were not strikingly successful, but it must be borne in mind that the generalized tuberculosis of guinea-pigs differs in many important particulars from the course of chronic pulmonary phthisis which is observed in human beings. In the former tubercle behaves as an acute general infection, but in the latter the tubercular condition is more of the nature of a local disease spreading slowly, and leading indirectly, rather than directly, to the destruction of vital parts.

It has been shown by A. G. Foulerton and A. M. Kellas† that high-frequency currents appear to have no direct bactericidal action, but that there is a production of ozone and of nitrous and nitric acids by the brush discharges of high-frequency apparatus, and that these exercise a strong germicidal effect upon cultures of bacteria. They express the opinion that when an ulcerated surface is treated by the brush discharge of a high-frequency apparatus the method may be regarded mainly as a means of bringing germicidal substances in an active condition into contact with the bacteria present in the lesion.

194. **Effects of X-ray Applications.**—Exposures to X-rays, if too long or too frequently repeated, set up a dermatitis of a very peculiar kind. Oudin‡ has given a graphic account of the changes which occur in the most severe form of X-ray dermatitis, and he describes the course of an X-ray " burn " as follows :

* *British Medical Journal*, October 12, 1901, and October 24, 1903.

† *Lancet*, April 25, 1903, and May 19, 1906.

‡ " Accidents dus aux rayons X," *Archives d'Électricité Médicale*, September, 1902.

At the end of one or two days (or even as late as two or three weeks) from the time of exposure a slight erythema shows itself, and this, instead of disappearing, gradually becomes of a red or livid colour, something like that of a chilblain, until at the end of a lapse of time which may be ten or twenty days, or even longer, the erythematous patch becomes the seat of troublesome irritation, which becomes worse and worse. Small vesicles or pustules develop on its surface, and these break and leave small ulcerations. Pigmentation of the surrounding skin develops during the same period, and the hairs may fall out.

Ulceration gradually involves the central part of the affected area, and finally a yellowish adherent leathery scab or crust forms, and remains unchanged for many weeks, the part being intensely painful. After the lapse of a longer or shorter time the necrotic patch separates, leaving a raw red surface which heals only very slowly, and may break down again from slight causes. Nothing in the way of dressings seems able to relieve the pain or to accelerate the healing process. It seems to be useful to apply some impermeable dressing, because the contact of air with the sore is quite painful. A year may elapse before the part heals.

The gradual onset after a latent period suggests that the lesion is a tropho neurotic one, due to the damage sustained by the superficial nerves of the part. Certainly there is partial anæsthesia in and around the affected area, which may persist for many months. After healing, the part may gradually acquire a nævoid character, and it remains irritable and tender for many years.

X-ray burns are specially produced by the rays emitted by " soft " tubes with a resistance of less than 3 inches of spark-gap.

Fortunately, X-ray dermatitis does not always follow this tragic course. In the earlier stages the symptoms may recede without the formation of a necrosed area, and this is most likely to follow if great care be taken to protect the part from every chance of accidental injury. So soon as the advent of a severe burn is apprehended, the part should be covered with cotton-wool and a bandage. No antiseptic lotions or ointments, no bathing with water nor poulticing, should be employed. The writer, by proceeding in this way, was fortunately able to arrest the progress of a serious burn on the dorsum of his hand. The part was covered with a layer of wool, and was sewn up in a

glove every day for three weeks. At the end of that time the livid œdematous condition had passed off, and the skin separated in one large piece, leaving a tender but healed surface beneath. Eight years have now elapsed since the time of the burn, which was produced as an experiment, and the area is now covered with nævoid patches (telangiectases) and is devoid of hair. Partial anæsthesia is still present, and the final stage of sound scar tissue does not seem even yet to have been reached.

The effects of a series of X-ray exposures of moderate duration are not quite the same as those produced by one or two prolonged exposures. Most X-ray burns of the severe kind just described have followed one or at least few exposures of inordinate length. In X-ray treatment it may be necessary to push the exposures to the very verge of causing dermatitis. In fact, dermatitis is often intentionally caused, and in experienced hands a sharp dermatitis can be set up without the disastrous sequels described by Oudin. It appears as though a tolerance were gradually established. At the same time, no one must fancy that there is any immunity from severe burns in such cases. Many severe burns have been produced during a course of treatment, but generally there is sufficient warning in the shape of harmless erythema to warn an experienced operator.

The amount of X-rays which can be administered with safety in one application can now be determined by Sabouraud's pastilles (§ 153), and single maximal doses are now often given.

Scholz* and also other observers have recorded a falling of hair or a production of dermatitis not only at the point where the X-rays entered, but also at their point of exit, the intervening tissues remaining unaffected, and this seems to show that destructive effects first manifest themselves upon the epithelial cells, although as soon as the injury has reached a certain intensity, an inflammatory action appears which manifests itself in a marked dilatation of the vessels, with gathering leucocytes and marked emigration of the blood-corpuscles.

The changes in the vessels are of importance as affecting the further development and healing of the ulceration.

It will be noticed that nothing is here given on the appearances presented by cutaneous nerves, and this is probably an omission of importance. The skin and the nerve structures seem to be peculiarly susceptible to injurious effects from X-rays, and

* *Archives f. Derm. und Syphilographie*, 1902.

this has also been observed with the similar radiations of radium.

A different form of dermatitis is seen in X-ray operators, in persons who are much engaged with X-ray apparatus or in the manufacture of X-ray tubes. In these persons the skin of the backs of the hands gradually becomes chronically inflamed and thickened, and cracks develop round the knuckles ; the hairs fall out, and are not renewed ; the nails become brittle, longitudinally striated and deformed, and the parts are irritable or intensely painful. Eventually ulceration sets in, and when this stage is reached treatment becomes almost ineffectual. A good photograph of this condition can be seen in the *Archives of the Roentgen Ray*, 1904, vol. viii. ; and a graphic account of his own suffering from chronic dermatitis has been written by Mr. J. Hall Edwards,* with photographs of the state of the hands in a severe case. Complete removal of the sufferer from all exposure to X-rays for a period of many months may afford relief. The use of lanoline also seems to promote recovery under those conditions.

Amputation of a finger has been necessary in certain cases, and death from development of carcinoma in the chronically inflamed tissues, with extension into the axilla, has ensued in one case at least.

Mr. A. G. R. Foulerton† has reported a case of squamous-celled carcinoma of the finger occurring in a surgeon who had suffered from severe X-ray dermatitis. The finger was amputated for intractable ulceration, and showed a condition of typical squamous-celled carcinoma, with cell-nests.

Conjunctivitis and retinitis have been known to follow X-ray exposures under the conditions causing chronic dermatitis in X-ray operators. X-rays have a destructive influence upon leucocytes, and repeated exposures cause a decrease in the number circulating in the blood, which has been turned to account in the treatment of leukæmia. At the German Congress of Internal Medicine, Drs. Linzer and Helber,‡ of Tübingen, stated that in small animals the blood could be almost denuded of leucocytes by repeated applications of the rays, and added that

* "On Chronic X-ray dermatitis," *British Medical Journal*, October 15, 1904.

† *Pathological Society's Reports*, 1905.

‡ Reported in *Lancet*, May 13, 1905.

the destruction of the leucocytes could be observed under the microscope in fresh preparations. They considered that the destruction of the leucocytes set free toxic substances in the serum, and attributed the nephritis observed in animals exposed to the rays to toxins formed by the destruction of the leucocytes. It has been stated that under the action of the rays lecithin is broken up, with the setting free of choline and methylamine, and the toxic symptoms sometimes observed in patients who have received large doses of X-rays might be explained by the results of this change. The X-rays do not appear to act upon the red corpuscles.

Higham Cooper* suggests that the X-ray burn is a trophic change due to the destruction of the nerve fibres of the skin, and points out that lecithin is an abundant constituent of nervous tissue.

X-rays have been shown by Albers-Schoenberg and others to exercise a peculiar destructive action upon the development of spermatozoa, so that male animals exposed to the rays become sterile, though their potency remains unimpaired. The sterility was found to be due to azoöspermia. In the female rabbit a similar destructive action upon the ova in the ovary has been observed to occur by Halberstaedter, though such an action in the human subject is not so well supported by evidence. Dr. Tilden Brown has reported on the results of the examination of the seminal fluid of seven workers with X-rays, and found spermatozoa absent in four of them, who had been exposed for the longest periods of time to the influence of the rays. It is not yet known whether the azoöspermia is temporary or permanent, but the condition is probably one which may be recovered from. A case has been reported by Cleaves in which both the disappearance and the subsequent reappearance of the spermatozoa was observed. The action of X-rays upon the development of hens' and of silkworms' eggs has also been examined and reported on. The effect of the rays seems to have been uniformly destructive.

X-rays are used in medical work in the treatment of many skin diseases, in lupus, rodent ulcer, and in malignant diseases. In the latter the results obtained are valuable, particularly in superficial epithelial neoplasms. But it is not the same with malignant tumours with marked tendencies to generalization.

* "The Action of the X-rays on the Tissues, with Special Reference to Leukæmia," *Medical Electrology and Radiology*, January, 1906.

Bergonié* has summed up the situation as follows : " In cancer of the breast, operable, with rapid invasion, in a young woman before the menopause radiotherapy cannot at present show any established successes, complete or lasting for more than a few months. In cancer of the breast, non-operable, in a young woman radiotherapy is a palliative treatment, diminishing or suppressing pain, closing superficial ulcerations, removing the fetor of the ichorous discharge, or even drying it up. But it does not prevent general involvement sooner or later. In cancer of the breast, recurring after operation, the conclusion is the same if the woman is young ; the results are perfect at first : the cicatrix becomes flexible, the epithelial nodules flatten out and disappear, the glands can no longer be felt ; but later on generalization takes place ; cough announces the mediastinal invasion, and one can only delay, not prevent, a fatal termination. In scirrhous cancer in older women, and in slow-growing forms of cancer of the breast, the results are much better. The X-ray will keep the patient for a long time free from pain, from ulceration, and from any considerable advance of the disease, and the treatment seems to be advantageous in every way."

In internal cancer the results are very seldom of any value. There may be some temporary relief of symptoms, but nothing more can be expected in the present state of our knowledge.

In sarcoma a certain small number of cases appear to have been benefited permanently. In tubercular affections of the lymphatic glands a certain degree of success has been obtained. In leukæmia great amelioration of symptoms may be produced—at least, for a time ; but it is not yet time to claim real permanent successes in this disease.

In tinea tonsurans X-rays afford a remedy of great value, and by their use the duration of the disease can be greatly reduced. The action is an indirect one, for the rays cause a temporary loss of hair in the parts exposed, and before the hair grows again the fungus has disappeared from that area. The rays have no direct action upon the ringworm fungus.

195. **The Action of Radium Rays.**—The rays of radium affect micro-organisms in varying degree. Non-spore-bearing bacteria are generally killed after two to fourteen hours' exposure. Spores may not be killed with less than seventy-two hours'

* "Sur l'État actuel de la Radiothérapie," *Archives d'Électricité Médicale*, August 12, 1905.

exposure. As the distance between the radium and the micro-organism is increased, the germicidal action becomes less marked, so that after thirty hours' exposure at one centimetre some may survive, and at ten centimetres there is little or no action.

Radium rays exert a marked retarding influence on the eggs of sea urchins. Spermatozoa are rapidly enfeebled and killed, and ova exposed to radium rays may develop irregular embryos by parthenogenesis.

The larvæ of insects kept in a tube with radium for twenty-four hours died in two or three days; in them, too, the nervous system was most affected.

Danysz* found that the action of radium on the skin is never immediate. At first nothing is felt, but on the eighth, fifteenth, or even twentieth day there is some congestion. This long latent period is one of the most interesting and mysterious facts about the action of Becquerel rays on living tissues. A sample of barium chloride containing about 50 per cent. of pure radium produces an appreciable congestion of the skin in a few minutes. If placed in contact with the skin of a guinea-pig for twenty-four hours, it causes complete destruction of the epidermis and dermis. The deeper connective and muscular tissues are little affected. If the radium be placed under the skin, a relatively feeble effect is produced on the connective tissues and muscles. The epidermic tissues seem to absorb the rays that produce the pathological effects. A tube of radium placed in the peritoneal cavity produced no lesions comparable to those produced on the skin, and the intestines and serous membranes seemed to be very slightly sensible to these radiations.

The nervous system is especially sensitive. A tube of active radium placed under the skin over the vertebral column and part of the cranium of a young mouse, one month old, caused at the end of three hours paresis and ataxia ; after seven to eight hours, tetaniform convulsions ; and death in twelve to eighteen hours. Mice, three to four months old, died with the same symptoms in three to four days, and those one year old in six to ten days. Guinea-pigs, eight to twelve days old, similarly treated for twenty-four to forty-eight hours, but with the tube applied to the lumbar region, suffered in one to three days from complete paralysis of the hind quarters and tetaniform convulsions. Death ensued in

* *Acad. des Sciences*, February 16, 1903. See also *British Medical Journal*, February 13, 1904.

six to eight days. Adult guinea-pigs and rabbits treated in the same way did not show any nervous troubles immediately, but died with skin lesions some weeks or months afterwards. An adult rabbit in which a tube was placed under the dura mater for eight hours showed nothing abnormal for two days, but on the third it had hemiplegia. It would seem, therefore, that the nerve centres sensible to these rays are protected by the bone in adults, but not by the cartilaginous tissues of young animals.

The effects on animals so far described were produced at close range, but the rays emitted by radium can also kill at a distance. London has found that if thirty milligrammes of radium be placed over a cage of mice for one to three days, the animals become ill on the third day, and die on the fourth or fifth. The first effects are redness of the ears and blinking of the eyelids; then follow drowsiness, refusal of food, slowness of movement, and feeble response to mechanical stimuli. At the fourth day there is coma, with paralysis of the hind legs. In deepest coma the spinal reflexes may be exaggerated, and the respirations slow and even scarcely appreciable. There is thus marked depression of the cerebral nervous system and exalted excitability of part of the cord. The respirations finally cease, and death occurs. The hairs on the back can be pulled out in masses, and often the epidermis becomes ulcerated. The chief histological changes are produced in the skin and cortex cerebri.

The effects of radium on the retina are interesting. When radium is placed near the eye, a sensation of light is perceived.

Radium rays give rise to burns of the skin like those caused by X-rays, and the scars of these burns are often deeply pigmented. Radium has been applied to the treatment of the conditions for which X-rays have been found useful. It has been successful in cases of rodent ulcer and in lupus.

In a case of telangiectasis plana (port-wine mark) of the whole left upper extremity eight spots of half a centimetre in diameter were exposed for ten minutes to radium rays by Dr. Holzknecht, with the result that eight spots of the same size, consisting of perfectly normal and white skn, were visible amidst the red surface of the nævus.

Several writers in this country have reported cases of rodent ulcer treated successfully by radium bromide. Mackenzie Davidson has published five cases treated with radium. The quantity used by him in these cases was five milligrammes. It

was enclosed in a tiny glass tube, and this was affixed with adhesive plaster to the affected part. Exposures of twenty or thirty minutes were given, and in some cases even longer. A reaction is produced on or about the eighth day, and is complete after the lapse of another fourteen days.

196. **Effects of Light Rays.**—H. Strebel has shown that light may act as a therapeutic agent by the light rays, by the heat rays, or by both together. The application of light containing heat rays from a number of incandescent lamps to the surface of the body increases metabolism, stimulates the formation of hæmoglobin and pigment, and produces general or local capillary hyperæmia. Such rays are an ideal sudorific, producing profuse perspiration without embarrassing the heart or respiration or causing other discomfort.

Some rheumatic patients are cured after using the light-chamber five or six times, others are improved, but others, again, are not benefited. The same has been observed in gout. Any improvement is probably due to the sweating produced, rather than to any specific action of the light rays. No marked improvement in the movements of stiff joints is observed. In nephritis the electric light bath is a safe and pleasant sudorific. In heart disease the effect varies according to whether the arc or the incandescent lamp is used as the source of light. The application of the arc-light, of which light rather than heat is the chief constituent, causes the pulse-rate to fall as much as forty to fifty beats a minute, probably owing to reflex vagus stimulation. With the incandescent light bath, on the contrary, the pulse-rate is increased. In the arc-light bath the diminished frequency of the pulse continues until the temperature of the chamber is sufficient to produce free diaphoresis ; the rate then increases, but never attains the frequency observed in the incandescent light chamber. The determination of blood to the skin greatly relieves the congested internal organs, and the sweating tends to diminish the anasarca, and so to relieve cardiac embarrassment. In obesity some loss of weight may follow. In anæmia the light of the arc has been found to increase the red blood-corpuscles and the percentage of hæmoglobin. The amenorrhœa of anæmia may be overcome by its use.

Strebel states that by the light-bath, and by local application of concentrated light to the chest, coryza may often be aborted, and chronic bronchitis with emphysema is often greatly

improved. Light without radiant heat has no effect in these cases.

Neuralgias and sciatica improve, though generally slowly, under light-baths. Radiant heat, and not light, however, is the important agent, since the arc-light is not effective if the temperature is prevented from rising by opening the ventilating doors.

On cutaneous diseases, and especially those of bacterial origin, the light rays and the chemical rays, as opposed to heat rays, are alone efficacious. In some cases of syphilis general light-baths, combined with local application of concentrated light, deprived as far as possible from radiant heat, appeared to give good results. The utility of the treatment by pure light rays is most evident in wounds and ulcers. Soft chancres heal rapidly, and even neglected varicose ulcers of the leg are cured in one to five weeks. Light is an excellent application to boils and acne. If the furunculosis is general, light-baths must be used as well as local irradiation. For most purposes Strebel prefers light with radiant heat. Freund* has given a very good historical account of the work done in the field of phototherapy.

In connection with the use of concentrated arc-light and violet and ultra-violet rays for the cure of lupus and for their bactericidal action, a valuable paper by J. E. Barnard and H. de R. Morgan should be consulted.† These observers found that the bactericidal effect was entirely confined to a portion of the spectrum commencing just beyond the edge of the visible violet end, and extending for a short distance only. They state that the active radiations lie between the wave-lengths of 3,287 and 2,265, or, in other words, in the middle third of the ultra-violet, as seen in the spectrum of carbon. Neither the extreme ultra-violet rays nor those nearest the visible violet appeared to be active in the destruction of cultures of micro-organisms. Similarly, they found that the rays producing the inflammatory reaction in tissues exposed to light were also confined to the ultra-violet, though they were not able to assign the exact wave-length in this case, as had been possible for the bactericidal action. They found that a lamp with iron electrodes gave out a quality of light which was more active than that given out by a carbon lamp.

197. **Special Effects of Coloured Light.**—A. V. Minine of

* "Elements of General Radiotherapy." Rebman, London, 1904.

† "The Physical Factors in Phototherapy," *British Medical Journal*, October 24, 1905.

St. Petersburg and Redard of Geneva have both stated that exposure to blue light has an anæsthetic effect, under which minor operations can be performed without pain. In this country H. Hilliard* has reported a number of cases in which the extraction of teeth was painlessly performed after the patients had gazed steadily for some minutes at an electric lamp in a blue globe held a few inches away from the eyes. The effects in Hilliard's experiments seemed to have been due rather to a hypnotic action than to the production of simple anæsthesia of the parts irradiated by the coloured light. Minine's† observations do not bear this interpretation, for his method consisted in the application of a fifty candle-power lamp close to the injured or painful part, and not in the exposure of the lamp to the patient's gaze. He describes several cases of joint injury and contusions in which much relief to pain was afforded, and the effusions were reduced by exposure of the injured part to the light of the blue lamp for ten or fifteen minutes. Similar results were not obtained with lamps of uncoloured glass, and from this the writer argues that the effect was not one of warmth alone. He also found the pains of gonorrhœal arthritis were much relieved by the same procedure. The effect of red light in preventing suppuration in small-pox vesicles may simply be due to the exclusion of the blue and violet rays, as has been suggested by Finsen, and is not yet to be regarded as a specific action of the red rays. There may be some inhibitory action upon the growth of streptococci, and the observations of Brieger on the good effect of exposure to red light in cases of chronic ulcer, and of Motchane‡ in a case of noma with perforation of the cheek and lip, seem to suggest this. In this case the light of a lamp of sixteen candle-power, with a red globe, was concentrated with a reflector upon the affected region, and was applied continuously for three days. At the end of that time the wounds appeared healthy, and cicatrization was in progress. No other local treatment was employed, and the writer attributed the cure to the use of the rays, but there may have been an action from the prolonged application of heat to the part, for non-luminous hot applications have been found useful in some forms of superficial ulceration.

* *British Medical Journal*, June 17, 1905.

† *Revue Internationale d'Électrothérapie*, July, 1900.

‡ *Ann. de Médecine et Chirurgie Infantiles*, July, 1905.

198. **The Use of Fluorescent Compounds.**—In order to augment the effect of treatment by light rays it has been suggested that some fluorescent substance should be given internally, or should be applied externally to the affected part. G. Dreyer and others have experimented with eosin and other fluorescent aniline dyes used as " sensitizers " in this way.

Professor von Tappeiner found that certain fluorescent substances which in darkness were scarcely toxic acquired in sunlight or diffuse daylight the power of destroying infusoria and of neutralizing toxins and enzymes. Even weak solutions of the substances in question exhibited this action. He had examined eosin, erythrosin, fluorescein, and other compounds. By the action of such substances ricin, for instance, lost not only its general toxic quality, but also its power to agglutinate erythrocytes; diphtheria toxin was rendered absolutely inert, and tetanus toxin was considerably weakened. By experiments on animals inoculated with diphtheria toxin it was found that the fluorescent compounds had also a certain therapeutic effect in increasing the action of exposures to light. Injections of eosin had a beneficial effect in rodent ulcer, lupus, and chancre.

Dreyer found that by the application of fluorescent substances the inactive, but penetrating, yellow and yellow-green rays could be made as bactericidal as the non-penetrating chemical rays (ultra-violet). The treatment was tried by Forchhammer on twenty-three patients suffering from lupus vulgaris, and included about 350 sittings. Erythrosin—in 1 in 1,000 dilution in physiological salt solution—was injected either cutaneously or subcutaneously, according to the situation of the lupus. Four to eight hours after the injection the light treatment was applied for from fifteen to twenty minutes. The action is generally as follows : The injections are usually but little painful, and no swelling, infiltration, or tenderness follows ; but within twenty-four hours of the light exposure severe pain sets in. Not infrequently the reaction of the light is like a phlegmonous process, and at times there is central necrosis. The same exposure of light without sensibilization does not produce this reaction The therapeutic result did not stand in proportion to the severity of the reaction. In one case the treatment was followed by an inflammatory infiltration, which lasted for several months, and from time to time an erysipelas-like erythema accompanied it. The same disappointing results were obtained in lupus affecting

the mucous membranes, for which fifty-four sittings were employed. Experiments were made to attempt to lessen the reaction by using weaker solutions of erythrosin, and by applying a less strong light, but he obtained no satisfactory results, and concludes that excessive pain and but little therapeutic gain is to be got from this form of treatment in its present position.

On the other hand, F. J. Pick and K. Asahi* have experimentally employed the eosin light treatment in certain cases, and have found it of much value. Instead of injecting the solution, they tried the method of painting the affected surface over with a 1 per cent. solution of eosin, and this painted part was then exposed to the direct influence of the sun, the other parts of the body being, when necessary, protected from the rays. Crusts or scabs were first removed by ointment or other means. In all twenty-two patients were treated in this way. Twelve were suffering from lupus, one from tuberculosis cutis verrucosa, five from trichophyton (tinea), three from scrofuloderma, and one from rodent ulcer. The lupus cases included lupus vulgaris, lupus serpiginosus, etc., and some were severe cases. In all they have found that the treatment was capable of removing the inflammatory appearances within a very short time. The changes were most marked in hypertrophic cases. In these the affected area became flattened, and in many instances the ultimate result was absolute healing. In the other skin affections they also obtained good results. The results in tinea were obtained in very short periods. In summing up, while they praise the action of the eosin light treatment, they state that they do not yet feel inclined to speak of actual cures in lupus, and that a much longer observation is necessary before one can be sure of the ultimate results.

W. J. Morton† has advocated the administration of solutions of substances which fluoresce in the treatment of patients by the X-rays or radium radiations, and claims that the patient's system is saturated thereby, and when any light capable of exciting fluorescence is applied the tissues will be flooded with the fluorescent light as deeply as the exciting radiations can penetrate.

Morton has used the method principally in deeply-located malignant processes, tuberculosis, etc., for which reason he has found it necessary to use the X-ray instead of the arc-light as

* *Berl. Klin. Woch.*, September 12, 1904.

† *Journal of the American Medical Association*, April 1, 1905.

an exciting agent, because the latter would not penetrate deeply enough to be able to excite the fluorescent phenomenon in the deeper tissues. The electric arc-light, therefore, would only be valuable in this method with lesions so superficial that the relatively feeble penetrating power of this light would suffice to go through the affected part.

As a proof that the tissues become fluorescent under the influence of the X-ray, it is said that the skiagraph of the hand of a person who has absorbed the fluorescent solutions shows a greatly superior detail and clearness, more especially of the osseous structures.

Morton employs quinine bisulphate in doses of from 5 to 15 grains daily ; fluorescein solution, 1 to 30, from 6 to 20 drops three times daily an hour after meals ; or from 5 to 15 grains of æsculine daily. He considers that it is a very valuable adjunct in the treatment of disease by the application of light or X-rays, and states that the excitation of fluorescence within tissue is a species of phototherapy, and that the fluorescent light compensates by propinquity to tissue for any lack of luminous intensity. The procedure has been received with a certain amount of scepticism, and has not been endorsed by other experimenters, though Béclère* has reported a case of sarcoma of the superior maxillary region in which X-rays combined with quinine lactate injected in 5-grain doses an hour beforehand seemed to have a better effect than that which was obtained either by the quinine or the X-rays when these were employed separately. The observations have not yet been generally confirmed in other cases.

199. **Magnetism.**—It seems to be rather doubtful whether any physiological effect has ever been observed to be due to the action of a magnet. Lord Crawford (then Lord Lindsay) and Mr. Cromwell F. Varley, with the help of an enormous electromagnet belonging to the former, were unable to perceive any sensation even on placing their heads between its poles. But in discussing these experiments in an address delivered at the Midland Institute at Birmingham, in October, 1883, Sir William Thomson came to the conclusion that it is just possible that there may be a magnetic sense, and, indeed, a committee of the Society for Psychical Research, who examined a large number of persons by placing their heads near the poles of an electromagnet, found three who were sensitive and were able to say

* *Arch. d'Électricité Médicale*, 1904, p. 498.

when the current was on or off. One of these persons was examined later by Professor W. F. Barrett, who found that when he was suffering from neuralgic pain it became intensified by the presence of a powerful magnet.

In some experiments conducted with very powerful electro-magnets by Dr. Peterson and Mr. Kennelly in Edison's laboratory, the results were entirely negative. The subject placed his head between the poles of a large electro-magnet, which could be excited from a dynamo-machine, and the authors concluded that the human organism was in no wise appreciably affected by the most powerful magnets known to modern science ; that neither direct nor reversed magnetism exerted any perceptible influence upon the iron contained in the blood, upon the circulation, upon ciliary or protoplasmic movements, upon sensory or motor nerves, or upon the brain."*

It has recently been proposed to treat patients by bringing them close to the end of an electro-magnet which is suddenly excited and demagnetized by a mechanical interruptor, the idea being the generation of secondary currents in the patient's tissues by the rapid changes in the magnetic field.

A. v. Sarbo† has used such an electro-magnetic apparatus, supplied by current at 100 volts, with infrequent alternations and of high intensity (10 to 40 ampères). He used it for various forms of neuralgia and of sciatica, lumbago, and muscular rheumatism, and states that many of his cases were cured. Improvement was obtained in a case of locomotor ataxy, with paræsthesiæ, for which latter the treatment was undertaken. In another case of the same disease gastric crises were successfully dealt with. In sleeplessness, some of which were uncomplicated cases, and others were depending on some other condition—for example, neurasthenia, hysteria, Graves' disease, etc.—two cases were not improved, while seventeen derived benefit from the treatment. The length of the treatment varied considerably, but, as a rule, patients could do without sleeping-draughts after from four to five sittings. It is doubtful whether this proposed mode of treatment is likely to survive. The effects produced may depend upon the production of induced currents in the regions of the patient which are brought near the magnetic pole.

* Paper, reprinted, with illustrations, in the English *Electrical Review*, August 18, 1893.

† *Deut. Med. Woch.*, January 8, 1903.

CHAPTER XI

ELECTRICITY IN GENERAL DISEASES

Anæmia and debility—Neurasthenia—Diabetes—Gout—Rheumatism—Rheumatoid arthritis—Leukæmia—Lymphadenoma—Tubercle and syphilis—New growths—Carcinoma—Sarcoma—Rodent ulcer.

200. **Anæmia and Chlorosis.**—In many forms of anæmia and in chlorosis we have to deal with simple forms of defective nutrition in which simple electrical stimulation suffices to bring about a change for the better. General electrization is not often resorted to for the treatment of these conditions, because good results can usually be obtained by other means. In obstinate cases where ordinary treatment does not answer satisfactorily the electric bath should be tried. By its use the metabolic processes of the patient can be so efficiently stimulated that increased appetite and vigour can be secured for the patient, with improved colour and a marked gain in weight. In chlorotic patients under these conditions the catamenia will probably be re-established. I have several times seen excellent results follow treatment by electric baths when anæmic patients were not doing well under iron, and consider that the results of general electrization are distinctly valuable in such cases.

201. **Delayed Convalescence.**—When the recovery of patients after serious illnesses is slow and unsatisfactory they should be treated by general electrization. After the specific fevers, and in many other conditions, electrical stimulation is of great value. After influenza a course of treatment by electric baths promotes the return of the patient's health to a normal standard. The mental depression disappears and the bodily strength returns, and the period of convalescence, which is so often prolonged in patients who have had an attack of this disease, is notably reduced. I have seen a rapid disappearance of serious mental failure after influenza under general electrical treatment by the electric bath. Tripier has stated that he had never seen

such rapid and remarkable good effects follow any other treatment in cases of anæmia, and especially in convalescence after acute illnesses, as those which followed general electrization.

202. **Nervous Debility and Neurasthenia.**—In neurasthenic states the methods of general electrization are of great value, especially the electric bath, which answers very well to the indications for treatment required by these cases. Direct applications to the nerve-centres with the constant current (§ 186) are also useful. The condition described under the general term "neurasthenia" is a condition of general debility or of debility affecting chiefly the nervous systems. Often it can be traced to some definite disturbing cause, such as mental worry or a severe illness; the digestion becomes impaired, and this keeps up a state of defective nutrition, from which it is difficult for the patient to escape.

In other cases errors or neglect in matters of diet, extending over a long time, may be the cause of the neurasthenia, and the patient himself may be quite unconscious of this. Dyspepsia is very commonly present, and should be attended to. Many people tend to become neurasthenic in the slighter degrees when their daily cares exceed a certain point, and when business matters or other troubles begin to spoil the appetite, and to interfere with proper exercise, with the regularity of meals, or with sleep, then troubles of the neurasthenic sort are likely to begin.

The treatment of neurasthenia requires the use of some method of general stimulation, and it is in this capacity that general electrization is so useful.

I have had opportunities of seeing the effect of general electrization upon a number of these cases, and I am satisfied that vigorous stimulation, carried out two or three times a week, in the electric bath with the induction coil or sinusoidal current, has far more effect upon neurasthenics than any other mode of treatment. It should be used in conjunction with proper rules for diet and regimen, and the original depressing cause of the disease should be found, and if possible, eliminated. If this cannot be done, no treatment will be of much use. For instance, where domestic unhappiness or discontent is a factor, one may treat in vain.

203. **Obesity.**—The treatment of obesity by electrical methods has been attempted, and Bordier states that it should be carried

out as follows: Large electrodes, well moistened, are applied to the thighs, to the abdomen, and to the lumbar region. Continuous currents are made use of, and if the electrodes are properly arranged, a magnitude of 100 or 150 milliampères can be borne.

Applications lasting half an hour or more are given. Care must be taken to avoid injury to the skin by a proper disposition of the electrodes, and by good conducting contacts between them and the skin surface. In addition, there may be a brisk stimulation of the muscles of the abdomen, thighs, and legs by a procedure of galvano-faradization. The pulse must be watched, and the treatment adjusted accordingly. F. Allard* prefers the sinusoidal bath, either the full bath or the four-cell bath of Schnée. In the former case 100 milliampères, and in the latter 40, may be used, repeated on alternate days. He states that he has been able to observe a reduction in weight ranging from 16 to 30 pounds after two months of this treatment.

204. **Rickets.**—This is another condition of simple defect of nutrition which is benefited by general electrization. It is surprising to see how quickly children with rickets begin to improve in general health, in their powers of standing and walking, and in weight, under the stimulating effect of electrical treatment. In Italy, Sagretti and Tederchi have reported a number of cases of rickets cured quickly and completely by electric treatment administered by the bath method.

Severe cases of rickets referred for treatment to the electrical department at St. Bartholomew's Hospital, and treated with sinusoidal baths, have fully borne out the accounts given by those writers.

205. **Diabetes.**—Much has been written on the treatment of this disease by high-frequency methods, and cures have been reported. In most of the recorded cases a notable reduction in the daily excretion of sugar has been produced, and the patient's condition has at the same time been improved. In spite of this evidence, it remains very far from certain that even a majority of diabetics respond to high frequency by a decrease in the amount of sugar discharged daily.

Other forms of general electrization seem capable of modifying the daily discharge of sugar. I have notes of several cases in which there was a striking diminution of sugar ex-

* *Revue de Thérapeutique*, March 15, 1905.

creted on the days on which electric baths were given, but in spite of this no real progress towards recovery was made.

206. **Gout.**—The application of electrolysis to the treatment of gout by means of salts of lithium is worthy of note.

The classic instance of this use of an electric bath is to be found in a communication of Mr. Edison's, read by Dr. Bayles of Orange, N.J., at the International Congress of Electricians held in Berlin in 1890.* Edison caused patients to dip one hand into a solution of lithium chloride of the strength of 5 per cent., and the other hand in a solution of common salt. After the passage of a current from arm to arm in this way lithium could be detected in the urine, and gouty symptoms were ameliorated after a prolonged course of these baths.

Guilloz† has reported two cases of severe and old-established gout which were successfully treated by local monopolar electric baths containing lithium carbonate. He used large currents up to 200 milliampères. To carry out this method of treatment the positive pole is to be placed in the bath with the affected limb, and the negative pole, of large size, is applied to the back, or may be applied through a second bath. The application should last from twenty to thirty minutes. Guilloz states that the first patient was twice treated for two severe attacks, each time with rapid good effect. The second patient also did well in spite of the fact that he continued to follow a dietary which was "of the most detestable," and that his excesses in eating and drinking were renowned ("passent a l'état légendaire").

Bordier‡ has published a case in which a treatment of the same kind was carried out. The patient had numerous large uratic concretions of both hands and of the elbows. Arm-baths containing 2 per cent. of lithium chloride were used, the circuit being completed through two large pads (kathodes) applied to the body of the patient; 80 to 100 milliampères were well borne, and the treatment was continued for half an hour daily.

After use for some days the liquid in the arm-bath began to deposit a sediment, and at the close of the treatment this was collected and analyzed. It was found to consist mainly of calcium carbonate, but contained undoubted traces of uric

* For an account of Edison's experiments, see Dr. Peterson's article on "Cataphoresis" in the "International System of Electrotherapeutics," by Bigelow and Massey (London, Henry Kimpton, 1902).

† *Arch. d'Électricité Médicale*, June, 1899.

‡ *Ibid.*, 1900, p. 531.

acid. At the end of a month the patient was much improved; the swelling of his hands had diminished by measurable amounts, and the tophi on the knuckles had become softened; one which was punctured discharged calcium urate in a semi-fluid state, whereas before treatment was begun they were quite hard and solid.

Direct currents of large magnitude passed through the affected joints are also worth a trial, for the ionic interchanges set up in this way have often proved useful in the relief of pain and swelling, even without the use of lithium or other special medicaments for the moistening of the pads.

General electrization has also been used in gouty conditions with the object of modifying nutrition in a favourable manner. The sinusoidal bath is very often valuable as a mode of treating these cases.

High frequency has been used in recent years for the general gouty state, but although some success has been obtained, yet it is to be noted that several cases have been recorded in which an attack of acute gout has seemed to have been determined by high-frequency applications.

207. **Rheumatism.**—The uncertain meaning which is possessed by the term "rheumatism" makes it difficult to deal with the electrical treatment of so-called rheumatic disorders. In acute rheumatism electrical applications to the joints have been found useful, but there is no great scope for the employment of electricity for that condition.

Clinical experience shows that muscular rheumatism is benefited by general electrization. Some writers have thought that the combination of direct with induction-coil currents (galvano-faradization) is specially indicated in such cases, and it is possible that the electrolytic action of the direct current upon the migration of the ions may tend to supplement the effect of simple stimulation produced by the induction-coil currents.

With chronic joint pains of rheumatic origin the local application of the battery current, by means of large pads, proves equally useful. Excellent results follow in patients in whom the joints continue to be stiff and painful after the subsidence of an attack of rheumatic fever.

Remak quotes a case where there had been rheumatic fever. The patient was ill for seven weeks in his own house and for ten

weeks in hospital. When discharged he was thin and pale, his joints were stiff, especially the knee and ankle joints, round which there was thickening. He was then treated by continuous currents applied to the several affected joints, and after six days of treatment was much more free from pain, had more power, and the thickenings had nearly disappeared.

Bordier,* in discussing the significance of muscular rheumatism, points out that the innervation and the nutrition of a muscle affected by rheumatism is clearly abnormal, the characteristic feature being the pain which is felt when the muscle is thrown into voluntary contraction. This condition of painful stiffness is so much like that which is felt in a muscle after a period of severe over-exercise that the inference may be drawn that in both cases the cause might be of a similar nature—namely, the presence of waste products in the tissue of the muscle. The good effects of electrical applications in so-called muscular rheumatism might be ascribed to the great effect which rhythmic tetanization or contraction has in promoting the flow of blood through the vessels of the contracting muscle, as by so doing the prospects of the removal of some of the waste products by the blood-stream would be notably increased, or the current may facilitate the elimination of toxic products. The ionic medication of "rheumatic" regions by salicylic acid compounds has been recommended by Leduc and other writers, and deserves extended trial.

208. **Rheumatoid Arthritis.**—This disease is one for which general electrization is undoubtedly useful. Applied in the form of the electric bath with sinusoidal current, general electrization is of great value in cases of rheumatoid arthritis. In many of my own cases marked good has followed this treatment, and the results in some of them have been most striking.

It cannot be said at present that a real cure of this disease can be achieved by electrical methods, and the results hitherto obtained are rather palliative than curative. Nevertheless, in comparison with the alternative modes of treatment the method of general electrization by means of the electric bath is perhaps the best at our command.

The obscurity which still surrounds the etiology of this disease makes all attempts at its treatment empirical, and although the electric bath is a very useful mode of treatment, yet it still

* *Précis d'Électrothérapie*, Paris, 1902.

leaves something to be desired. So far as individual cases are concerned it would be easy to relate instances of remarkable improvement following treatment by the electric bath, but from time to time cases are met with which seem to show no improvement at all from this method. Rarely, it may even appear to aggravate the complaint. This has been my experience in a few cases, and a possible explanation may be that if the commencement of the electrical treatment should happen to coincide with an acute exacerbation, the treatment may be unable to arrest it, although at a more favourable period, when the attack is over, it may be of service in reducing the damage done.

It is possible that future progress in the electrical treatment of rheumatoid arthritis may lie in the direct application of large currents to the individual joints, and it is not improbable that the introduction of drugs by electrolytic action into the immediate surroundings of a joint may form a part of this method of treatment. Following the lines suggested by Professor Bouchard, who has indicated that a small quantity of a drug injected locally may have as great an effect at that point as a large quantity administered by the mouth, Dr. Roques and others have employed the electrolytic introduction of ions of salicylic acid into the surrounding tissues,* and have secured encouraging results. The use of tannic acid in direct current baths has recently been suggested for the treatment of rheumatism.

Apart from this introduction of medicaments by electrical means, it is likely that the copious interchange of ions which is produced by the passage of large direct currents through a part may have an important action in modifying nutrition in a joint affected by rheumatoid arthritis.

It may be worth noting in this place that the characteristic appearance of joints which are the seat of rheumatoid arthritis is a thinning of the cancellous tissue of the bones in the neighbourhood of the affected joints. Sometimes overgrowth of the margins of the articular surfaces may be recognised.

Dr. Bertram Abrahams,† in a paper read before the Clinical Society, considers that four different conditions are confounded together under the name of rheumatoid arthritis—viz., a disease occurring in children, described by Dr. Still ; an acute process occurring in young women, described by Dr. Hale White ; the

* *Arch. d'Électricité Médicale*, 1903, p. 689.

† *British Medical Journal*, April 22, 1905.

well-known multi-articular affection of middle-aged women; and the chronic malady of the aged. The non-articular arthritis of the hip-joint is considered to be a separate condition by many writers, some of whom attribute it to injury and others to senile change. Very little can be done by electrical methods for the relief of the last-mentioned condition.

209. **Leukæmia.**—The treatment of leukæmia by applications of X rays has excited great interest during the past few years, and numerous reports of the favourable influence of the treatment upon the symptoms of this disease have been published in this country and abroad. A very full account of the X-ray treatment of leukæmia will be found in a paper by Dr. Ledingham and Dr. McKerron,* and the conclusions there arrived at represent the position as reached at the present time.

In the X-ray treatment of leukæmia there may be great improvement in the patient's symptoms, and in his general condition; but it is not yet certain that the rays exert any permanent effect in removing the underlying morbid condition. Relapses on the suspension of treatment are frequent, and in many of the apparently successful cases the patient has ultimately died of his disease. The mode of treatment is to apply the rays to the region of the spleen and to the spine, and to those regions of the bony skeleton where red marrow is most abundant. At the commencement of a course of treatment there may be a transient increase of the number of white cells in the blood, but they soon diminish very largely, and may even reach a normal number. A pyrexial condition has often been observed during the treatment, and has been attributed to toxic products of the destroyed white blood cells. Ledingham and McKerron in their paper point out that the effect of X-rays in leukæmia is very similar to the effect upon the disease of an intercurrent affection. Dr. Owen T. Williams has shown that X-ray applications in leukæmia produce a marked increase in the excretion of nitrogen and of uric acid, and that there are signs of disintegration of leucocytes, and he draws the conclusion that sufficient intervals of time should be allowed between successive applications to allow the body to excrete these toxic products and to prevent the development of constitutional disturbance.

* "The X-Ray Treatment of Leukæmia." Report of a case, with an abstract of the literature. *Lancet*, January 14, 1905.

Aubertin and Beaujard* have recorded two cases of leukæmia treated with X-rays, with observations on the effect on the different varieties of leucocytes. One case was a myelogenous leukæmia with the classical splenomegaly, and the other a lymphatic leukæmia with marked hypertrophy of the cervical, subclavicular, axillary, and inguinal glands, together with considerable enlargement of the spleen. In each case identical treatment was used: for several months there was a weekly application of the rays of the same intensity, but in the one case applied over the spleen and the myelogenous tissue of the bones, and in the other over the spleen and the lymph glands. The general state in each was rapidly ameliorated; the red blood-corpuscles in the course of three months were increased by one-third—from 2,000,000 per cubic millimetre to 3,000,000—and the leucocytes fell in the myelogenous case from 320,000 to 60,000, and in the lymphatic case from 350,000 to 10,000. In the myelogenous case there was noticed a marked increase in the leucocytosis after each of the earlier séances, reaching to 450,000, occurring three to five hours after the application of the rays, and lasting three or four hours. The polynuclear leucocytes were responsible for the principal increase, or, as the authors term them, leucocytes in histolysis. In this case the improvement in the leucocyte state was mainly qualitative; the diminution in number was established only after a long period of increase, with marked oscillations. The body-weight was maintained in spite of great reduction in the size of the spleen, the appetite was increased, albuminuria and œdema disappeared, and a feeling of well-being was established from the earlier days of the treatment. In the lymphatic case a similar increase of the leucocytes was noticed a few hours after the séance—thus, starting at 349,800, at the end of five hours they numbered 372,000, falling to 346,000 at the end of the ninth hour. By the seventh day they had fallen to 253,200, by the twentieth day to 171,600, and by the twenty-seventh to 26,000; by the beginning of the third month they had fallen to 10,000, and five days later to 3,000, at which level they remained. A qualitative amelioration did not become prominent until about a month before the onset of this leucopenia of 3,000, the polynuclears increasing little by little. The red cells increased progressively to 3,100,000 from 2,130,000, the richness in hæmoglobin rose from 20 to

* *Archives Générales de Méd.*, March, p. 577.

80 per cent., the spleen diminished considerably, the lymph glands became nearly inappreciable, and the general state improved.

Bozzolo has reported the effect in cases of relapse, which had improved under X-ray treatment, but had slipped back on the cessation of treatment. He found that even in relapses the X-ray applications were able to act promptly and speedily in bringing back the blood to its normal condition and improving the general condition of the patient. It was frequently noted that although the patient appeared quite well in his general health, and the spleen much reduced, yet the blood condition still showed pathological alterations, and in these cases the X-rays soon reduced the percentage of leucocytes and increased the hæmoglobin. The state of the blood in all these cases was liable to considerable fluctuation from time to time. We are not certain as to the exact way in which the X-rays act in these cases of leukæmia or pseudo-leukæmia, but probably the rays first exercise a specific action on the follicles of the spleen and later on the bone medulla and splenic pulp tissue. In those cases where up to now the only satisfactory treatment has been removal of the spleen, an alternative treatment is clearly suggested by the application of X-rays. In medullary leukæmia splenectomy is useless.

Higham Cooper, in referring to a case of leukæmia treated by him with the application of X-rays,* has collected a number of similar cases from current literature. In his patient, a woman of twenty-nine, there was considerable reduction in the size of the spleen after three weeks' treatment. The splenic area and the ends of the long bones were exposed for ten minutes three times a week, using a regulator tube with 4-inch spark gap, and 20 volts 5 ampères on the primary. There was a slight inflammatory reaction, and treatment was discontinued. The leucocytes were reduced from 62,000 to 8,500 ; the red corpuscles remained about the same in number. He also alludes to a case recorded by Rhode of Copenhagen, in which before treatment the leucocytes were 236,000, the red corpuscles 2,500,000, and the hæmoglobin 40 per cent., with the spleen reaching to within an inch of the iliac crest. After a month's treatment the leucocytes were 7,200, the reds 4,000,000, and the hæmoglobin 60 per cent. At the end of the second month the leucocytes were 4,000, the hæmoglobin 70 per cent., and the spleen of about

* *Med. Electrol. and Radiol.*, March, 1905, p. 68.

normal proportions. Higham Cooper concludes his paper with the statement that the application of the rays seems to produce a destruction of lymphatic tissues, and also a toxæmia, and that it does not seem clearly established whether or no these conditions are the result one of the other.

210. **Lymphadenoma.** — N. Senn, of Chicago, has recorded a case in which X-rays seem to have cured a patient suffering from this disease. A man, aged forty-three, had extensive enlargement of the cervical, axillary, and inguinal glands, and of the spleen. The disease began in the cervical glands a year previously. X-rays were applied, one minute each being allowed for each side of the neck, one minute each for front and back of neck, and one minute for each axilla, each groin, and the spleen. The tube was used at 12 inches distance. A month later the glands were diminished, and the skin over the chest showed erythema. The coil was then operated less strongly, but blisters formed on the chest, and the neck, naturally dark, turned dark brown. From April 16 to 23 the exposures had to be confined to the neck, back, and groins, as the chest was the seat of extensive burns. On the 24th all the glands exposed to the rays had nearly disappeared, and the hair on the part of the head exposed and in the axillæ and on the pubes had fallen off. The neck was blistered and the nipples were discharging pus. The treatment was suspended. Two weeks later the patient was much improved, and was able to return to business. No enlarged glands could be discovered. When seen again on August 1 he felt well, but had recently noticed slight enlargement of the cervical and axillary glands. The enlarged glands were treated again by exposures of two minutes for each group, with a current of 28 volts and 6 ampères, and the swellings again disappeared.

F. Williams* has recorded a case in which the glands were much enlarged in the neck, axilla, groins, and mediastinum; the spleen was also much enlarged. The patient, a girl of twelve years of age, was greatly improved in all respects by X-ray applications, but subsequently the disease recurred, and she died two years later.

Zum Busch recently showed a case before the Clinical Society† in which a patient with symptoms of an extensive mediastinal

* Allbutt's "System of Medicine," vol. i., p. 517, with plates.

† March 23, 1906.

growth had been greatly benefited by a course of X-rays. It was regarded by one of the speakers as a case of lymphadenoma, but by Dr. Busch as one of lympho-sarcoma.

In a case of lymphadenoma under my own care no good result followed the repeated application of X-rays.

211. **Tuberculous Diseases.** — The treatment of tuberculous affections by electricity has been extensively tried, and with some success, so far as the relief of certain of the local manifestations of the disease are concerned. Some of these local conditions will be considered in detail in a later chapter, but it will be useful to take a general view of the situation here. In lupus X-rays have given ample proof of their power in promoting the healing of ulcerated surfaces, and on this account X-rays are now extensively used in the treatment of this disease.

They are least successful in cases in which there is little ulceration, and it has been pointed out by Sequeira and others that certain foci of the disease may remain latent in an apparently healed area, and may break out again at a later date. The form of tubercular disease of the skin known by the name of " verruca necrogenica " responds very favourably to X-ray treatment.

High-frequency currents are also useful in lupus, particularly for the treatment of the disease in the nose or in other parts which are difficult of access with X-rays. In such cases a glass vacuum electrode (§ 144) of suitable shape is very convenient. Ionic medication has been tried for lupus, but hitherto with scant success, though it is quite possible that a good method of employing this mode of treatment may in time be discovered.

Tuberculous glands also respond favourably to X-rays. Bergonié has reported a series of four cases treated for non-suppurating tuberculous glands, and states that he considers the action of X-rays to be markedly good. All the glands treated became reduced in size, but did not disappear completely.

M. Dovaston* has reported a case in which a large mass of glands on one side of the neck disappeared under X-ray treatment, leaving a perfectly formed neck on that side. On the other side a surgical operation for the removal of a similar mass of glands had previously been performed. The X-ray treatment occupied nine months in all. M. Hendrix† has published

* *Lancet*, February 10, 1906.

† *La Polyclinique* (Brussels), June 15, 1905. Abstract in *Lancet*, August 5, 1905.

notes of three successful cases, and notes that the first sign of improvement was a softening of the inflammatory tissue between the glands, so that their individual contours could be felt. This was also mentioned by Dovaston. Hendrix says that the larger glands leave behind them a kind of cicatricial residue, but the smaller ones disappear entirely, so far as palpation is able to determine this. Rudis-Jicinsky* has also recorded good results in this condition. The same writer has reported† in detail a series of successful cases of tuberculous joints, and speaks highly of the value of X-rays in this condition. Dr. Alex Gregor‡ has published an interesting case of a boy with a tuberculous knee-joint cured by X-rays, applied in consequence of the production of improvement by X-rays used for photographing the joint.

Mr. Sydney Stephenson§ has recorded a case of tuberculosis of the conjunctiva cured by X-rays after thirteen exposures; and W. B. de Garmo‖ a case of tuberculous testis treated successfully in the same way.

In a case, supposed to be tuberculous, of angular curvature of the spine in an elderly man, associated with great pain and weakness in the back, and with a lump the size of a walnut on the sacrum, I found that the application of X-rays produced a marked effect upon the pain within a week, and this was followed by a gradual disappearance of the tumour on the sacrum and a consolidation of the vertebral curvature. The patient made a complete recovery, and the sacral lump had disappeared entirely at the expiry of four months from the commencement of treatment. A year later there had been no return of the trouble.

Chanoz and Lévêque¶ have reported three cases in which the direct current proved valuable in cases of tuberculous joint. In one of these Lévêque was himself the patient, and the results of treating his own knee for tuberculous hydrarthrosis were perfectly satisfactory to himself. In two other cases the joints treated were notably improved. The currents used ranged between 20 and 50 milliampères. The electrodes were of large surface, and were placed on either side of the affected joint.

* *American Medicine*, December 17, 1904.
† *New York Medical Journal*, August 7, 1904.
‡ *British Medical Journal*, January 28, 1905.
§ *Ibid.*, June 6, 1903, with figure.
‖ *Medical Record*, April 15, 1905.
¶ *Arch. d'Élect. Méd.*, 1903, p. 264.

In pulmonary tuberculosis the recorded results are less satisfactory. Cures have been reported after electrical applications of the most varied kind, and particularly after X-ray and high-frequency treatments; but there is not as yet any body of convincing evidence to sustain the belief that a cure of phthisis by electricity has yet been achieved.

212. **Syphilis.** — In this disease there is not yet much gained for electrotherapeutic methods. The obstinate ulcerations sometimes met with as a late symptom may be encouraged to heal by X-ray applications, but not with any particular rapidity.

In leprosy X-rays have been tried, with some degree of success. Radium has also been suggested for use in this disease. Radium has been found to destroy the toxin of rabies, but apparently it is necessary to expose the virus so long that the use of radium in the disease is not practicable as a mode of treatment.

213. **New Growths.**—X-rays have been extensively tried in many kinds of new growth, though more particularly in malignant diseases. Among benign neoplasms it appears that warts and other papillomata and some kinds of lipoma are favourably influenced by this treatment. The introduction of the ions of magnesium from a solution of magnesium sulphate has the effect of causing the disappearance of the common warts of the hands.

214. **Carcinoma.**—The use of X-rays in the treatment of cancer has had an enormous development in the last few years, but the failure of the method to achieve a real cure of the disease has led to disappointment, in spite of the fully-established fact that in X-rays we have a palliative mode of treatment which is of high value in many cases.

In looking through the published records of X-rays in cancer, one cannot help noticing that few of the alleged successful cases have been really complete, and this, too, in spite of the fact that hundreds of cases have been treated.

In short, while there is a quantity of evidence to support the contention that X-rays act beneficially in malignant disease, the amount of evidence to show that cures have resulted is lamentably meagre, and we cannot yet suggest any explanation why an agent which very commonly gives relief to some of the symptoms produced by a malignant growth should fail to give the complete relief which is really required, and we are almost forced to believe that it must be from some inherent defect of the method of a fundamental kind.

It is abundantly clear that X-rays have a striking influence in promoting the healing of superficial cancerous ulcerations, and in causing the disappearance of the lymphoid nodules which are so commonly seen as the first signs of recurrence around the scar of an amputation of the breast. The following case was one of recurrence after removal of the breast, and the patient eventually died of her disease.

When first seen she had an ulceration of the right pectoral region, measuring 4 inches in one diameter and 5 in the other. Treatment with X-rays was given four times a week for two months with a few omissions. A few days after the treatment was commenced signs of healthy cicatrization began to appear round the margins of the ulcer. This continued to advance until the healing process had extended inwards from the margin for a distance of fully $\frac{1}{2}$ inch all round. The new epithelium was deeply pigmented. The centre of the wound assumed a healthy aspect, and appeared to be in process of healing all over. But at this time the patient suffered a spontaneous fracture of both the femur and the humerus from secondary deposits in the bones, and the X-ray treatment was suspended in view of the hopelessness of the future of the patient. The total number of exposures was seventeen, and many were made with the ulcerated surface covered by dressing or bandage. After the suspension of the X-ray treatment, the process of healing still went on quite steadily, until at the time of her death, a month later, there was a firm and healthy scar covering the whole surface except about 1 square inch in the centre. This portion was also a healthy healing surface, though not yet covered over by epithelium. Thus nineteen-twentieths of the area of a cancerous ulcer had healed up in three months as a consequence of X-ray applications, but, nevertheless, there was no influence upon the spread of the disease in the remote parts of the body.

With regard to the histological changes resulting from the action of the X-rays on cancerous growths there is not much to be said. According to W. F. Brook, the epithelial elements of the cancer disappear, but the fibrous tissue remains unchanged, the loosening of the adhesions being due rather to general relaxation from diminution in bulk than to any dissolution of cicatricial tissue. In a case under his care in which the "lump," after fifty exposures, gradually increased to three-quarters of

an hour, was reduced to half its original size, excision was performed, and an examination of the tumour was made by Mr. Shattock, who reported to the Pathological Society of London that no degeneration of any kind or cell lysis had been induced in the carcinomatous epithelium, no phagocytic invasion of the epithelium was in progress, and on every side the growth was in an extending condition. The clinical diminution in size of the mass and the loosening of its deep connections were difficult to explain; possibly they were due to the disappearance of a subinflammatory œdema.

E. A. Codman* has reported that at the Massachusetts Hospital many cases of deep malignant disease have been faithfully exposed, but few had essentially improved and none had been cured. There had been a few encouraging signs in some cases, as relief from pain, gain in weight, shrinkage, softening, breaking down of the tumour.

In a discussion on the X-ray treatment of cancer at the British Electrotherapeutic Society in March, 1906, several leading members admitted that they had no cases of genuine successes in cancer to relate, although they had had numerous patients under their care for X-ray treatment; but Mr. Chisholm Williams was able to report ten cases of carcinoma and sarcoma published by him a short time previously† in which a lasting cure seemed to have been attained.

It has been suggested that the best mode of employing X-rays in malignant disease is to commence at an early date after the removal of the growth by operation, before any evidence of recurrence has shown itself, in the hope of preventing recurrence by destroying any microscopical foci of disease which may have escaped removal. Not much evidence has yet been collected as to the value of this procedure, but the idea is a rational one. In a patient under my own care a course of X-ray applications was given soon after the removal of enlarged glands from the cervical region. The breast had been removed on a previous occasion. After treatment by X-rays had been continued for two months some suspicious thickening was felt underneath the scar of the second operation wound. An operation was performed and the suspicious region was excised. A microscopical examination revealed fibrous tissue containing a few cells of

* *Johns Hopkins Hospital Bulletin*, May, 1903.

† *Lancet*, November 4, 1905.

suspicious character, but not of such a kind as to enable a diagnosis of carcinoma to be made with any certainty. It is interesting to remark that the tissues removed at the operation which preceded the use of X-rays were distinctly carcinomatous, with abundance of epithelial elements, and it is therefore quite possible that the X-ray applications had altered the character of the recurring growth in a beneficial way, although they had not succeeded in preventing recurrence altogether.

In the secondary deposits which follow squamous-celled epithelioma X-ray applications are likely to provoke severe reaction, with breaking down of the mass, and also with exuberant growth all around. On this account it is prudent to exercise extreme caution in the X-ray treatment of this class of case, if, indeed, it is not better to decline to use X-rays at all for them.

The proposal to use X-rays before an operation for removal of a malignant growth is probably unsound, because harm is likely to follow delay once an operation has been decided upon.

The treatment of cancerous growths by electrolysis has been proposed, to produce sloughing of parts of a cancer, when nothing else can be done.

For many years G. Betton Massey,* of Philadelphia, has employed metallic electrolysis (§ 189) in cancer cases. In his method actual destruction of the central portions of a superficial malignant growth is combined with a diffusion of ions of a metal such as zinc or mercury into the peripheral parts, and he has been able to observe that there is an undoubted effect in arresting the malignant growth in a zone lying outside the portion which has been destroyed by sloughing as a result of the treatment. Dr. Massey attributes this to the action of the metallic ions which have diffused away from the electrode, and he lays especial stress upon the need for allowing a sufficient duration of time to the electrolytic treatment, in order to permit of a sufficient diffusion, as this is a comparatively slow process.

The currents used have ranged from 350 to 1,800 milliampères, the duration of the application lasting one hour, or even longer.

* "The Treatment of Cancer by Electrical Destruction and Regional Sterilization through the Cataphoric Diffusion of the Electrolytic Salts of Mercury and Zinc" ("An International System of Electrotherapeutics," London, Henry Kimpton, 1902).

In a recent paper Dr. Massey states that about 20 per cent. of his cases have been satisfactorily cured. A. Granger,* of New Orleans, endorses Dr. Massey's method, and says, further, that as a cure or a palliative for malignant disease within the mouth it has proved of especial value.

215. **Sarcoma.**—W. B. Coley,† reporting on sixty-eight cases of sarcoma treated by X-rays, states that in six cases complete disappearance was observed, but in every one of them there was a recurrence within a few months from the time of the disappearance of the disease. In two of these cases the recurrent growths subsequently disappeared when injections of the mixed toxins of erysipelas and *Bacillus prodigiosus* were added to the X-ray treatment. These two cases remained well, although in one nearly two and a half years, and in the other one year, had elapsed since the disappearance of the last recurrent growth.

Coley's paper deserves study, as it is clearly and simply written, and gives detailed histories of a number of interesting cases. He tells us that he had inquired into the subsequent fate of several reported cures of sarcoma, and had found that in general the patients had afterwards died, even although the X-rays had caused complete disappearance of undoubted sarcomatous tumours. He concludes his paper with the following remarks, which will be endorsed by all who have had sufficient experience in this class of case :

"The results of the treatment of sarcoma with the X-rays thus far have shown :

"First, that the great majority of cases are but little affected by the use of the X-rays.

"Second, that in a certain small proportion of cases the tumour decreases rapidly in size and, in a few instances, may totally disappear.

"Third, that in all of the cases so far observed, with one exception, there has been either local or general recurrence, although in some few cases life has undoubtedly been considerably prolonged.

"Fourth, the very small percentage of cases in which the tumour has disappeared and the almost universal tendency to early recurrence even in these cases are sufficient reasons for never advocating the method except in inoperable or recurrent cases."

* *Trans. Amer. Electrotherapeutic Association*, 1904.

† *Archives of Physiological Therapy*, April, 1906.

I have myself observed an instance of complete disappearance of a rapidly-growing round-celled sarcoma of the jaw, in which the patient, after remaining free from recurrence for a twelve-month, has again begun to show a suspicious thickening in the region of the scar, although so far no evidence of deep recurrence has revealed itself. Thus we have in sarcoma, as in carcinoma, the strange phenomenon of the profound influence exercised by the rays, with a strange insufficiency so far as final cure is concerned.

216. **Rodent Ulcer.** — All those who have worked at the therapeutics of X-rays are agreed that their effect in this disease is satisfactory, and numerous successful cases have been published of late years.

Considerable progress has been made in the direction of shortening the time necessary for the treatment of a case by the use of larger doses of X-rays at a sitting. This procedure is safely performed by the use of the pastilles of Sabouraud and Noiré, already described, and it is not unlikely that small rodent ulcers may soon be successfully treated by a single application of X-rays pushed up to the degree of causing a mild dermatitis. For this to be safe it is necessary that the surrounding parts be properly screened. The effect of X-ray treatment undoubtedly persists for some time. Thus, Hall Edwards* advises that the exposure should be continued until a well-marked erythema surrounds the ulcer, and that treatment should then be stopped, and has found that, as a rule, no further treatment will be necessary, for in the course of a few weeks the healing will have been completed. He considers that the effect of the rays may go on for a period of six weeks or more after the suspension of the raying, if the total dosage has been sufficient. He finds that eight, ten, or twelve exposures usually suffice.

It is the case that the effect continues even when it has been insufficient. Thus, an elderly patient who was under treatment at St. Bartholomew's was obliged to discontinue his visits after eight times, on account of severe bronchitis. On his return six weeks later he said that improvement had continued for a month of his absence, but that matters then became stationary, and as he was not quite cured, he wished for further treatment. A few more applications sufficed to complete the case.

The question, formerly much debated, as to the proper kind

* *Treatment*, June, 1903, vol. vii.

of X-ray tube to be used for rodent ulcer is now practically settled. A soft tube, having an equivalent spark resistance of about 3 inches between point (positive) and plate (negative), is the most suitable, because its rays are more completely absorbed by the skin than are the rays of harder tubes, and with such a tube the maximum amount of rays which can safely be given at one time should be employed. The procedure should be repeated at the end of four weeks if necessary. In the extensive rodent ulcers met with in hospital practice it is better to proceed more cautiously, using weaker doses of the rays more frequently.

Radium can also be used with great advantage in the treatment of rodent ulcer. Mackenzie Davidson has described his mode of procedure, which consists in applications of the radium tube to the surface of the ulcer for thirty or forty minutes. After this a reaction shows itself on about the fourteenth day, and takes another fourteen days to subside. Healing takes place during this latter period, and the application may be repeated after five or six weeks from the time of the first application.

Another electrical method of treating rodent ulcer is the electrolytic one, with ions of zinc. Leduc first indicated this method, and it has been developed in this country by the writer, in whose hands it has already been successful in eighteen cases. Details of the operative procedure will be found in a paper* in the *Lancet*, with notes of seven cases.

These results seem to be of considerable promise for the future. The condition of the ulcer at the time of the application is an important factor, for to obtain a successful effect requires an evenly distributed action of the zinc over the whole area of the ulcer, and in many instances this is rendered difficult by the state of its surface, which may be partly crusted over, conducting badly, and partly moist and raw, conducting well. Then, too, the advancing pearly edge of the disease is partially shielded by its layer of epidermis. In these ordinary circumstances the distribution of current, and therefore of the zinc ions, is an unequal one, and some portions of the ulcer receive a better quantity of the zinc ions than other parts.

There are still several small details of practice to be worked out in this electrolytic employment of zinc ions. At present

* Lewis Jones: "Some new Lines of Work in Electrotherapeutics," *Lancet*, October 28, 1905.

I use a solution of zinc sulphate at the strength of 20 grains to the ounce, and this seems to answer well. There is no question of caustic effects, and the treatment produces no additional scarring; indeed, the healed part may show hardly any evidence of the former existence of the rodent ulcer. The magnitude of current to employ depends upon the surface under treatment. Leduc has suggested a strength of 2 milliampères per square centimetre, applied for about fifteen or twenty minutes. In my experiments I have used rather stronger currents for proportionately shorter time. The treatment causes some slight pain or discomfort if the current has too great a density, but in general the little operation is well borne. If that is not the case, it is easy to introduce a little cocaine first, using a separate pad for the purpose.

The electrodes are discs or spirals of zinc wire, and can easily be made. The metal is covered by lint or cotton, tied on in some cases, and in others the lint is applied to fit the part under treatment, and the metal held upon its surface. The zinc ions seem to remain in the cells of the affected part for some time, or at least the effect set up by the application seems to continue for a considerable time afterwards. For instance, in one of my patients, where it was evident on September 6 that the pearly edge of the rodent ulcer treated on August 30 had not disappeared, it was decided to allow another week to pass before repeating the application, and a week later this edge had become very much less definite, although nothing further in the way of zinc electrolysis had been done to it. Another patient, writing a month after the electrolysis, stated that the spot was smaller, but not gone, but after another month, without further electrolysis, the spot had so completely disappeared that its exact site was difficult to locate. The appearance of the rodent ulcer at the end of the application is peculiar. When the zinc ions have penetrated thoroughly, it has a milk-white look, rather disquieting in aspect until one is familiar with it; but this dead-white colour does not mean that there is going to be any necrosis of tissue, and seems merely to be the proper appearance of a tissue impregnated with zinc ions. The white colour slowly fades away and leaves the surface rather sore for a week or more. During this period a little zinc lotion or ointment may be applied, but there must be no question of repeating the electrolysis for at least a fortnight or three weeks. The depth

to which the zinc ions can penetrate in a given time is also a matter requiring investigation. The rate of movement of ions in an electrolytic conductor has been determined, and in the case under consideration is probably less than a centimetre in an hour, the actual figure being influenced by the magnitude of the applied electromotive force. The amount of zinc set in movement in an ordinary application of 10 milliampères for ten minutes is about 4 milligrammes. The effect of the applications is, therefore, strictly local.

CHAPTER XII

THE NERVOUS SYSTEM—THE PERIPHERAL NERVES

Electricity in diagnosis—The motor points—Relation of spinal nerve roots to muscles—Practical testing—The reaction of degeneration—Treatment of paralysis—Injuries of nerves—Neuritis—Special nerve injuries and diseases—Neuralgia—Brachial neuritis—Sciatica.

217. **Electrical Testing of Nerves and Muscles.**—The examination of the electrical reactions of the muscles is often of great assistance in the diagnosis of cases of paralysis. Even those who are indifferent to the therapeutic actions of electricity are accustomed to attach importance to the electrical reactions as an aid to diagnosis.

An electrical test often gives distinct evidence in cases where without it one could only guess at the morbid condition of the affected parts. The following history affords a useful instance of its value: A patient had an accident with broken glass, cutting himself in several places. As the ulnar nerve showed signs of injury, the wounds were carefully examined. In two of them near the wrist the nerve was found to be divided, and was sutured. In the other wounds the nerve could not be seen, and it was thought to have escaped injury at those points. No electrical test was made at the time. Some weeks later an electrical examination was sought, as the limb remained paralyzed. It was then found that the flexor carpi ulnaris showed a reaction of degeneration, which proved that the nerve had undoubtedly been divided in another of the wounds, which was above the elbow. On exploration the nerve was found to be divided at that point, and was joined. Later the case was tested again, and the report was given that the nerve was in process of repair, and wanted only time and electrical treatment to recover its functions. After this the patient remained for some time with but slight signs of improvement, and a further exploratory incision was made which put aside all doubts as to the existence

of reunion of the nerve. With time the patient made a good recovery. Another patient with a wound of the hypothenar eminence, who complained of vague pains and weakness in the hand, was shown by electrical testing to have a reaction of degeneration limited to certain of the intrinsic muscles of the hand, caused by division of the ulnar nerve in the centre of the palm by a spicule of glass which had penetrated deeply.

Electrical testing depends upon the fact that the normal reactions may become changed as a result of disease or injury. The changes looked for are changes in the visible responses given by the muscles. As there may be changes in the behaviour of the muscle either to interrupted or continuous currents, both forms of electrical excitation are used in the examination of a muscle. The testing is usually done with the active electrode (§ 68) applied to the muscle itself, at or near to its motor point. The testing electrode may also be applied to the nerve trunks, at a distance from the muscles, to determine their power of conducting motor impulses, their conductivity being shown by the movements of the muscles to which they are distributed ; but it is to the muscles that the testing electrode is generally applied, as the individual contractions of each muscle can be better seen in this way.

In testing a muscle the electrodes required are the indifferent electrode (Fig. 54) and the electrode handle with ' closing ' key (Fig. 51). The former is to be placed over any convenient and remote part of the body; thus the patient may hold it against his chest, or it may be slipped down the back of the neck, so as to be held in place by the pressure of the clothing, or with a patient lying down it can be placed beneath the hips, or finally, if the patient is lying on his face it may be placed over the sacrum. In any case it must touch the skin with even and firm pressure throughout the process of testing. Both the electrodes and the surface of the body concerned must be well moistened with warm salt and water, and the more thoroughly this preliminary moistening is done the more satisfactory will the testing be.

In testing the intrinsic muscles of the hands and feet, and with a few other muscles, as, for example, the deltoid, it may be convenient to apply both electrodes over the part in such a way as to cause the current to pass right through the region under test ; thus the interossei are most easily thrown into action with

the indifferent electrode under the palm and the active electrode on the dorsal aspect of the hand.

Again, for testing the muscles of the legs a very good position is for the patient to lie prone, with the indifferent electrode held by an assistant over the lumbar spine, the leg to be tested being flexed and supported vertically. In this position all the leg muscles can be reached, and the foot is free to move in any direction in response to the contractions of the muscles as they are tested.

The active electrode or testing electrode should be of small surface; one which is three-quarters of an inch in diameter is very suitable. Its surface may be slightly convex.

218. **The Motor Points.**—These are the points to which the testing electrode should be applied in order to set up a contraction most easily in the subjacent muscle, or they are points at which motor nerve trunks can be easily reached. They represent positions at which a maximum effect can be produced by a given current, and a good knowledge of the motor points enables one to carry out a test with comparatively weak currents, and therefore with the least amount of discomfort to the patient. Many diagrams of the motor points have been prepared, most of them being based upon von Ziemssen's plates (see Plates I.-VI. at the end of this volume).

These plates were prepared by exploration of the surface with a testing electrode, and marking the points as they were found. Dissections on the dead body show that the most excitable spots correspond to points at which the main nerve supply enters the muscle.

The motor points are not quite constant for different individuals; their exact places vary a little in different cases, but not so greatly as to diminish the value of knowing their positions. The best position of the electrode can be readily found by moving it about in the neighbourhood of the usual position of the motor point of any particular muscle until the vigour of the contraction shows that the exact spot has been touched. The ease with which the motor points can be found depends a great deal upon the amount of subcutaneous fat present, and the examination of the deeper muscles is always more difficult than the superficial layer; indeed, in the case of some of the deep muscles it is almost impossible to produce a contraction limited to the muscle sought, because the diffusion of the current throws the neighbouring superficial muscles into action, and obscures the result. It is

important to place the patient's limb in a good position, so that any muscular movement looked for may be readily seen ; the muscles must be lax ; the limb should be supported by the hand of the operator, and not lying flat upon the table or couch. It is best to begin with a current which is enough to throw the muscle into strong contraction, and to apply it only for a very brief moment at a time ; in this way the process of testing will be sooner over. It is well always to try the strength of the current on one's self before touching the patient.

It is assumed that the action of the individual muscles is known, so that when a contraction is produced it can be referred to its proper muscle. Besides watching for and seeing the movement produced by the contracting muscle, one may place a finger upon the tendon to feel any movement, or one may see slight movements in the fibres of the muscle itself even when they are too feeble to move the limb.

219. **Relation of Spinal Nerve Roots to Muscles.**—Frequently it happens that paralysis affects a group of muscles, and one may wish to trace back their nerve supply to the spinal roots. For example, the distribution of a paralysis affecting some of the muscles of the hand might enable us to distinguish between a lesion of the trunk of the median nerve on the one hand and a lesion of the first dorsal root on the other. In the latter case the whole of the thenar and hypothenar eminences, and all the lumbricales and interossei would be involved ; in the former case many of these muscles would escape—namely, the hypothenar muscles, the interossei, the two inner lumbricales, the adductor pollicis, and the inner half of the flexor brevis, all of which are supplied by the ulnar nerve.

Many writers have given lists of the muscles of the upper limb with the segmental arrangement of their nerve supply, and although these lists present minor differences they agree in a general way with one another. In the *Medical Annual* for 1904, under the heading ' Brachial Plexus,' will be found an extremely useful paper by Dr. William Thorburn. After comparing the views of different anatomists, he gives a table from which the following list is compiled :

Nerve Roots—*Fourth Cervical.*—The spinati (and probably the rhomboids and teres minor).

Fifth Cervical.—Deltoid, biceps, brachialis anticus, supinator longus and brevis (coraco-brachialis very probably).

Sixth Cervical.—Subscapularis, pronator teres, and quadratus, teres major, latissimus dorsi, pectoralis major (part), (pectoralis minor probably), serratus magnus, triceps.

Seventh Cervical.—Triceps, extensors of wrist.

Eighth Cervical.—Flexors of fingers.

First Dorsal.—Intrinsics of hand.

The flexors of the wrist and the extensors of the fingers are less precisely known, but they are certainly distributed between the seventh and eighth cervical roots. In the lower limb the segmental arrangement is much less clearly known, but it is most probable that the third lumbar segment supplies the psoas and iliacus, the adductors of the thigh and the sartorius; the fourth lumbar supplies the quadriceps and the adductors, and the fifth lumbar the hamstrings; while the leg and foot muscles must be assigned to the first and second sacral segments, the intrinsics of the foot belonging doubtless to the second sacral level. The perineal muscles (levator ani, etc.) are probably supplied from the third sacral, and the bladder and rectum from the fourth sacral segment (Thorburn).

The segmental distribution of the sensory nerves has been worked out by Head and others, and diagrams of the body surface showing the segmental areas are to be found in most of the text-books of nervous diseases.*

220. **Practical Testing.**—When a fair degree of skill in finding the motor points has been acquired, the chief difficulties of testing the reactions of a patient's muscles will disappear. Nothing is so useful for the student as to practise frequently upon his own muscles. Half an hour spent in picking out the motor points, and in observing the relative sensitiveness of the skin in different parts of the body, and in noting the effect of a thorough moistening of the skin before applying the testing current, will well repay a beginner.

It is a useful rule always to apply the current to one's self at the commencement of a test. The patient feels reassured if he sees this done, and the chance of the current being too strong is decidedly lessened. The easiest method is as follows:

Place the indifferent electrode in position upon the patient and moisten the skin of the part to be tested, then grasp that part with one hand, and apply the testing electrode to the back

* See H. H. Tooth, "The Segmental Spinal Sensory Areas Clinically Considered." (*St. Bartholomew's Hospital Reports*, 1905.)

of the hand which is holding the patient; then on closing the key the current will pass to the patient through the hand of the operator, who will be able to judge of the strength of the current by the sensation produced. One should commence testing with interrupted currents and finish with continuous. There is seldom need to use very strong currents.

When testing with the continuous current begin with about twenty volts for the limbs, or half that pressure for the face. Let the testing electrode be the kathode, and note whether a closing contraction is visible, and if none is seen, increase the current until it appears, observing the readings of the galvanometer. When the closing contraction is obtained, note the effect of moving the electrode, in order to find the most effective spot for stimulating the muscle; compare the ACC with KCC (§ 172), and take especial notice of the nature of the contraction to see whether it be quick or sluggish. Next compare the contractions obtained by direct stimulation of the muscle with the effect of stimulating it indirectly through its nerve trunk. Lastly, note the results methodically in the form of a report.

When the affected parts can be compared with the corresponding region on the opposite and sound side of the body, it is not difficult to perceive changes in the electrical reactions. When the disease is bilateral this is not so simple, and one must depend to a certain extent upon previous experience, and upon comparisons with one's own reactions; but, wherever possible, the comparison of the affected muscles with their fellows of the opposite side of the body is a matter of the first importance.

221. **Changes in the Electrical Reactions.**—The changes which may be found in the reactions as the result of disease or injury are classified as follows:

1. Quantitative changes or changes in the amount or quantity of response to stimuli, the character or quality of the reactions not being otherwise changed.

This includes simple increase of excitability and simple decrease of excitability to coil and cells, changes which are usually spoken of as *quantitative* changes.

2. Qualitative changes or changes in the nature or quality of the reactions. These include the reaction of degeneration, both complete and partial, the myotonic reaction, the myasthenic reaction, etc.

3. The condition of total loss of all visible contractions, both to coil and to cells, must also be considered.

222. **Quantitative Changes.**—In unilateral disease increased or decreased excitability is shown by differences in the behaviour of the two sides. If the normal side be used as a standard for purposes of comparison, an increase of excitability will be inferred if the minimal contraction shows itself with a lesser current on the affected side. If both sides are affected, then an increased excitability may be inferred if the minimal contraction is seen with currents which are weaker than those which the operator has learnt to recognise as usual in healthy people. The diagnostic value of small qualitative changes is not very great, so happily their determination is not of the first importance.

The recognition of increased or decreased irritability is easy when the increase or decrease is considerable, but to diagnose slight increase or slight decrease demands great care, as there are many disturbing factors to be guarded against. Careful attention to galvanometer readings is the best guide, but even then one has to consider the differences which may depend upon the place of the testing electrode, for a slight movement away from the motor point will make the current less effective, and so will simulate a decrease of irritability. Again, unequal pressure of the electrode, when comparing two points, may cause an apparent difference in irritability, for with increased pressure the electrode is pushed nearer to the nerve or muscle, and is rendered more effective. The resistance of the skin may also vary during a test, and as it usually falls while the testing is in progress, this may complicate matters. Sometimes the resistance in a paralyzed limb is much increased, through alterations in the condition of the skin which covers it.

Increased irritability occurs usually in those conditions in which increased reflexes are found. Both signify increase of irritability in the central nervous system. It is observed in chronic myelitis, in degeneration of the lateral columns, and in hemiplegia, also in tetany, in which disease it becomes a prominent feature.

Diminished irritability occurs in many diseases. It is seen in the milder forms of those injuries and diseases which show qualitative changes when they are more severe—for example, in acute anterior poliomyelitis a reaction of degeneration will be found in some of the paralyzed muscles, while others will only

show simple decrease of irritability. In neuritis, too, both traumatic and other, one may see either qualitative or quantitative changes, according as the attack is severe or mild.

Simple fatigue may cause decreased irritability. In myasthenia gravis, decreased irritability, coming on during the progress of the testing, is a striking symptom. A progressive decrease in the response to a series of stimuli may often be noted in muscles whose reactions are enfeebled.

The electrical properties of the testing circuit have a decided influence upon the apparent excitability of nerve and muscle, and this introduces fresh disturbing factors when the results of testing with one apparatus are compared with those of a different one. Dubois* has shown that the presence of a high degree of self-induction in the testing circuit tends to lower the stimulating effect of the current by retarding the rate of growth of the current at the period of closure. Thus a stimulus is effective in proportion to the suddenness with which the current rises to its maximum, and the greater the self-induction of the circuit the slower this rise becomes.

223. **Qualitative Changes—The Reaction of Degeneration.**—This term was introduced by Erb to signify the combination of altered electrical reactions which occurs in the nerves and muscles under certain definite morbid conditions, the most characteristic feature being that there is an alteration in the quality of the response which the muscles make to the continuous current, the contraction provoked being a slow and sluggish one, differing greatly in its character and appearance from the rapid twitch given by a normal healthy muscle.

The reaction of degeneration is characterized by the loss of all excitability in the nerves and of the excitability to rapidly interrupted currents in the muscles, whilst the excitability of the latter to continuous currents remains, and is sometimes notably increased, but undergoes a definite and peculiar modification, the contraction set up being slow or "sluggish."

This reaction of degeneration (usually symbolized by the abbreviation RD) is of very great importance, and its value consists in the fact that when it is present we can diagnose a lesion in a certain part of the nervous tract. A lesion causing the reaction of degeneration must be situated in the lower neuron, either in the gray matter of the anterior horn in the

* *Arch. d'Électricité Médicale*, 1898, p. 1.

cells from which the nerve fibre starts, or else somewhere in the course of the nerve fibres passing from there to the muscle. The reaction of degeneration does not follow lesions of the upper neuron, nor does it follow affections which are confined to the muscle fibres proper (idiopathic muscular atrophies).

In RD the irritability of the nerve disappears entirely, and therefore stimulation of it, whether by interrupted or continuous currents, has no effect ; the muscle, on the other hand, retains its irritability to certain forms of electric stimulation. Though it does not react to rapidly interrupted currents, it can react to a mechanical shock, or to a current whose duration is not too brief. It differs from a curarized muscle, for this will still react to brief interrupted currents directly applied, and therefore the loss of irritability seen in a muscle with the reaction of degeneration signifies something more than a failure of the intra-muscular nerve endings, and probably means that a trophic change has occurred in the muscle protoplasm. Interpreted in the light of Ioteyko's researches (§ 172) it would signify a failure of the striated elements of the muscle, and a survival of the sarcoplasmic components. The production of ACC more easily than KCC, which may often be seen in the reaction of degeneration, is a further evidence of the change which has occurred. This alteration of the relative effect of the poles is not an essential part of the reaction of degeneration, for it is not constantly present, although it was formerly thought to be an invariable concomitant of the reaction of degeneration. Another important alteration is that the irritability of the muscle to the continuous current may be greater than in health, strong contractions being set up in the affected muscles by currents which are too weak to produce any visible movement in the neighbouring healthy muscles.

It is only in fairly recent cases that this exaltation of muscular irritability is manifested, and in most cases of RD of long standing a progressive decrease of irritability in the affected muscles is observed.

224. **The Longitudinal Reaction.**—In muscles showing a reaction of degeneration it will be found that a contraction is more easily elicited when the testing electrode is applied at the distal end of the muscle than when it is at the motor point. This effect was first noticed by Remak in 1876 in a case of wrist-drop due to lead, but it has only received attention in recent years,

and has been described by Doumer as the "longitudinal reaction." It appears as though the motor point lost its importance, the longitudinal reaction being produced by direct stimulation of the muscular fibres, the reaction at the motor point by stimulation of the muscle through its nerves.

The longitudinal reaction is of great utility in electrical testing, and an examination for it should never be omitted. It affords a means of eliciting a contraction in old-standing or severe cases when the irritability of the muscle is so reduced that contractions are difficult to obtain with the electrode on the motor point. It also helps to confirm a diagnosis of reaction of degeneration when the test applied at the motor point leaves the operator doubtful as to whether it is 'sluggish' or not. If in such a doubtful case the test with the electrode on the distal tendon gives a stronger and slower contraction than can be obtained at the motor point it is certain that degenerative changes exist in the muscle.

Again, it may happen that the contraction obtained with the electrode on the motor point is passably quick, while that obtained distally is decidedly slow. This probably signifies a degree of injury which is less severe than one giving a sluggish movement for both situations of the testing electrode, and it is a phenomenon which may often be observed if looked for.

225. **Partial Reaction of Degeneration.**—This term is applied to cases in which some degree of contractility for brief interrupted currents is present, although there is decided sluggishness of contraction of the muscle for the continuous current.

The existence of 'partial RD' makes it important in testing always to confirm the results of the induction coil test by the application of the continuous current test. If partial RD be present there is usually a perceptible alteration in the coil reactions, but this may be overlooked, and in that case conclusions drawn from the presence of coil reactions alone would seriously mislead. Between partial RD and complete RD there are various degrees of alteration. The sluggishness of contraction may vary within wide limits: the reaction to the coil may be very faint or fairly strong.

Since its formulation by Erb the group of signs which go to make up the reaction of degeneration has held its ground as the central feature of electrical testing for a generation, but the whole situation is badly in need of further analysis. So long as

the recognition of 'sluggishness' is a matter of the operator's judgment the test by Erb's method will be unsatisfactory. The preceding paragraphs have indicated that it may be very difficult in certain cases to determine whether 'sluggishness' is present or not. Also the nature of the interrupted current employed in testing is in need of revision. Indeed, it is possible by employing a very slow interrupted current to produce a condition like that of tetanus in a muscle which is the seat of a marked reaction of degeneration, and gives no response at all to interrupted currents of the kind generally used.

226. **Practical Difficulties in Testing.**—Those who are familiar with electrical testing are well aware of the fact that notable variations in degree are to be seen in the reaction of degeneration. Some of these are certainly due to a general degradation of the state of the muscle in cases of long standing, which makes the contractions more difficult to see, and deprives them of some of the sharpness of character which one might expect. Examples of this kind in which the RD can still be observed, but which are not good cases for the demonstration of typical RD are common enough. The polar change with predominance of ACC over KCC is referred to by Professor Erb as one of the most constant phenomena in medicine, but, in the opinion of many workers, the phenomenon is so inconstant a part of the reaction of degeneration as to be without diagnostic value. It is possible that the relative order of appearance of ACC and KCC may be influenced by chance positions of the testing electrode. See Fig. 171 for the virtual polarity of parts around an electrode. Thus a positive electrode near to a motor point, but not exactly over it, might set up a virtual negative polarity at the motor point, and *vice versâ*. Again, the degree of sluggishness, or, in other words, the duration of the contraction produced in muscles by the closure of the current from the cells, varies within a wide range, so that at times one may see a contraction so long and slow as to resemble a veritable peristalsis of unstriped muscle, while in other cases it is only after a careful comparison with sound muscles that one can at last determine whether the contraction is or is not to be called slow.

There are two directions along which the study of electrical reactions should be prosecuted. One of these is by the graphic method, using a recording apparatus to trace the curves of the muscular movements, as has been done by Mendelssohn. The

apparatus used is a combination of key electrode with a tambour for receiving the impulse of the contracting muscle, and transmitting it to a revolving drum. It was described by Radiguet, and is made by M. Verdin, 7 Rue Linné, Paris. The other is along the line of measurements of the durations and the frequencies of the interruptions needed to set up the muscular contractions.

The commutator of Leduc must come into use, and it is probable that in the near future a report on the electrical testing of muscles will include a statement of the minimal duration of current to which a muscle can react visibly and of the critical frequency at which a muscle responds to an interrupted current in the same way as to a continuous current—namely, by a single twitch at closure, followed by quiescence. Both these phenomena can be established for normal muscle, and undergo profound changes in disease. It is also probable that different muscles of one and the same individual show physiological differences in this respect, though this is at present only suspected.

227. **Conditions which lead to the Reaction of Degeneration.**—We have already seen that RD follows damage to the lower neuron—that is to say, to that part of the course of a motor fibre which commences at the ganglion cell of the nucleus of origin, or its equivalent in the anterior cornu of the cord, and is continued down as a nerve fibre to the motor end-plate beneath the sarcolemma of its muscle, and a certain degree of severity in the damage is necessary to produce it. RD is therefore found after division, injury, or disease of the motor nerve trunks, of the ganglion cells in the anterior cornu of the cord, or of the corresponding nuclei of origin of the cranial nerves. Under one or other of these morbid states can be grouped pressure palsies of all kinds, division or contusion of nerves, different forms of toxic or other neuritis, anterior poliomyelitis, both acute and chronic, also acute and chronic myelitis. The reaction of degeneration is not found in the paralysis of cerebral disease, except when the implication of the nuclei of origin, or of the nerve trunks of the cranial motor nerves produces a reaction of degeneration in the muscles which they supply; nor does it occur in diseases limited to the white matter of the cord, nor in hysterical paralysis.

228. **The Course of the Reaction of Degeneration.**—After a nerve-trunk injury the course of events and the times at which

they take place will naturally depend upon the nature of the injury, and on its severity. It is generally stated that after section of a nerve there will be a transient period of increased irritability. This is immediately followed by a progressive decrease, and by the end of a week or ten days the irritability of the nerve will be completely abolished, and will remain so until recovery takes place.

In the muscle the decrease of irritability to interrupted currents goes on to complete disappearance in about the same time, but by the end of a week the response to battery currents begins to show an increase of excitability, with sluggishness of contraction, and sometimes with ACC > KCC. Subsequently a diminution of excitability sets in, and if recovery is not to take place the diminution is progressive, until at last contractility may disappear entirely.

J. Sherren* found in his cases of section of nerve trunks that the affected muscles cease to respond to the interrupted current in from four to seven days, that at about the tenth day it may be extremely difficult to obtain any response to stimulation with the constant current, and that the characteristic sluggish contraction with polar reversal makes its appearance about this time. He did not observe disappearance of reactions in cases of long standing, and adds that in the cases he had watched (up to nearly two years) the muscles reacted to stimulation with the constant current during the whole period between injury and recovery. In cases which recover it usually happens that the power of voluntary movement will return some little time before the response to electrical stimuli. A slight response to coil currents is the first change to be noticed in the reactions, and this will be noted when the response to the battery currents is still sluggish and feeble. Sometimes the muscle will begin to show a coil reaction, when stimulated through its nerve trunk, before it responds to a similar stimulus applied directly to the muscular fibres.

229. **Prognosis in the Reaction of Degeneration.**—The student must not fall into the error of looking upon the occurrence of a reaction of degeneration as in itself indicative of irreparable mischief, and conversely normal reactions may be consistent with absolutely incurable lesions, involving complete paralysis.

* Erasmus Wilson Lectures "On the Distribution and Recovery of Peripheral Nerves." *Lancet*, March 17, 24, and 31, 1906.

Inasmuch as the electrical test can only give information as to a certain portion of the nervous system—namely, the lower neuron—if inferences are to be drawn from the observations made it will be necessary for the observer to take many other circumstances into consideration in order to arrive at proper conclusions.

After operations for suture of divided nerves, and in most other cases of injuries to nerves, the chief need on the part of patient and surgeon is patience. After division of a nerve recovery is slow, especially if an interval has passed between division and reunion ; reactions of normal quality are slow to reappear, particularly when there is a long stretch of nerve between the wound and the muscle tested. The most distal muscles suffer the most, and regain power and reactions the latest.

In the simplest cases of division followed by immediate successful suture a considerable time will elapse before any return of voluntary power can be recognised in the paralyzed muscles. Three months may be considered a short time to wait. In these favourable cases the sluggish contraction to cells will continue to be present, and to be fairly strong throughout. If an interval of time passes between the division of the nerve and the operation for suture the reaction will probably have undergone some decrease in strength, and may even have disappeared at the time of the operation for suturing.

If this has happened recovery will be very slow, and the appearance of a sluggish RD contraction may be the first change for the better in the electrical reactions.

Sherren tells us that in five cases of primary suture of the ulnar nerve at the wrist motion first returned to the paralyzed muscles, on an average, in 50 weeks after suture. In three patients the appearance of the hand became again normal in 12 months, 20 months, and 2 years after suture. In two instances of division of the nerve at the elbow, in one 100 weeks elapsed before voluntary power returned to the muscles of the hand ; in the other the flexor carpi ulnaris regained voluntary power and reacted to the interrupted current 66 weeks after suture, but no recovery had taken place in the muscles of the hand 17 weeks later. After division of the median nerve at the wrist voluntary power returned to the paralyzed muscles on an average 40 weeks after suture.

Sherren found in his cases that the return of irritability to interrupted currents coincided with the return of voluntary power, and says that in no case of suture of the nerves of the forearm which he had watched had voluntary power returned before irritability to interrupted current.

The following note illustrates the opposite experience: A patient, aged twenty-seven, had resection of the musculo-spiral nerve in May. In December there was visible voluntary movement of the extensors of the wrist, though not enough to move the wrist-joint. In the following February examination showed that there was fair voluntary power in the radial extensors of the wrist, but no reaction to interrupted currents. In April the radial extensors of the wrist were thought to show a faint flicker of response to the interrupted current, but no other extensor muscles showed any trace of reaction until a month later. Improvement continued, and the patient made a good recovery.

Among the practical points which continually arise in connection with the RD, perhaps none are more important than the giving of an answer to the question whether a nerve trunk is divided or only hurt. The question is one of the utmost importance, because the whole future conduct of the case rests upon the answer, and it may be difficult to answer it because RD will equally follow division and severe injury. Perhaps it will be useful to consider an actual case. A barber on board ship was at work with a pair of scissors when the vessel gave a heavy roll and the patient accidently plunged the scissors into his armpit. It bled a good deal, and was bandaged up tightly, and remained so for several days until the ship came into port. He was then found to have an extensive paralysis of the forearm and traumatic aneurysm of the axilla. I was asked to report on the paralysis, and to state whether any nerves were divided or not. He showed RD in the ulnar and musculo-spiral areas. In the latter area one muscle, the triceps, did not show complete RD, for it retained its contractility to the coil in part, while in the ulnar area the paralysis was not absolute, the wasting was not extreme, and sensation, though impaired, was not altogether lost. On these grounds the report was given that the musculo-spiral nerve was not severed, and that in all probability the ulnar had also escaped. His nerve trunks accordingly were not explored, and under treatment by electricity he made a gradual but complete recovery. His paralysis probably had been

caused by the tight bandaging and not by the punctured wound.

Another case was one of gunshot wound of the lower half of the arm with extensor paralysis. It was examined electrically about three weeks after the accident, when healing of the extensive lacerated wound had made good progress. There was RD of all the extensors, but wasting was not extreme, the contractions were of very good volume, and the sluggishness was not conspicuous. Judging that if the nerve had been completely severed the reaction of degeneration would have begun to enter the stage of decreased irritability, and finding it to be not decreased an opinion was given that the trunk of the musculospiral had escaped. The later history of the case proved this opinion to have been correct.

It would add very much to the value of electrical testing if it gave reliable indications which made it possible to distinguish between severance of a nerve and serious injury without severance. Sherren has endeavoured to find such differences, and in his lectures* he mentions a form of reaction which he regards as typical of incomplete division. It is characterized by a loss of response to interrupted currents, and an increased readiness of response to continuous currents, which is less sluggish than that of well-marked reaction of degeneration, and is described by him as brisk, though not the sharp twitch given by sound muscles.

230. **The Myotonic Reaction.**—The ready production of duration tetanus (§ 172) is sometimes observed. It is connected with the reaction of degeneration, and may be confounded with it. The myotonic contraction is something analogous. It occurs in Thomsen's disease, and is characterized by a peculiar response of the muscles to electrical stimulation. These are thrown into prolonged tetanic contraction by interrupted and by continuous currents, and the state of contraction persists after cessation of the stimulus for a period lasting from five to thirty seconds, and then fades away gradually.

Rich has described a variety of polar change in which the KOC contraction appears readily. This is suspected in testing with moderate currents and using the kathode, if an opening contraction is produced in addition to the ordinary closing contraction. Rich considers that this reaction is peculiar to cases

* *Vide supra*, p. 394.

of compression of nerves, such as may occur after the use of Esmarch's bandage.

231. **The Myasthenic Reaction.**—A peculiar reaction (the so-called myasthenic reaction) is met with in the muscles of these patients. The peculiarity consists in a rapid decrease in the amount of response shown by a myasthenic muscle when it is tetanized continuously by the interrupted current. In other words, a myasthenic muscle shows the ordinary physiological effect of fatigue with excessive and abnormal rapidity, so far as the tetanizing effect of the interrupted current is concerned; but in spite of this it seems to remain just as responsive to the application of a single closing shock from a direct current source after the tetanization as before. This peculiarity has been interpreted to signify that the seat of disease in myasthenia gravis is not in the muscle fibres, but must be in the nervous elements.

232. **Treatment of Paralysis.**—Certain fundamental principles of treatment apply to nearly all cases of paralysis. If possible the seat of disease in brain, cord, or nerves should be included in the treatment, as well as the paralyzed muscles. The seat of disease is to be treated in the hope of setting up beneficial changes there, and the muscles are to be treated in order to maintain and stimulate their nutrition. Stimulation of the peripheral parts acts upon the central organs through the medium of the sensory nerves, and in a reflex manner may send motor impulses along the nerves to the paralyzed muscles. When the paralysis is purely motor, and the sensory functions of the affected parts are normal, this reflex mode of stimulation is of importance, and it follows that peripheral sensory excitation of a limb in infantile paralysis, or of the face in Bell's palsy, is a rational procedure.

Sometimes a muscle can be made to contract through its nerve earlier than by direct applications to its motor point, and direct stimulation of the nerve-trunk, by applying one electrode above the seat of injury, with the other below, may prove useful. Most electrical treatment is now carried out by using a single active electrode and an indifferent electrode (§ 68). The active electrode may be three or four inches in diameter, according to the extent of surface to be included in the treatment, and the magnitude of the current used; the electrodes must be well moistened with warm salt and water, the indifferent one in its

sheath is then pushed down the back of the neck for patients who are dressed and sitting up, or it is placed under the hips for patients lying down. The part to be treated is then bathed with the same solution, and the active electrode applied, and the current slowly raised to a proper strength, with the battery current three, five, or ten milliampères, or more if necessary. The active electrode is then moved slowly over the whole of the affected part (*labile* method), or it is kept still in one place (*stabile* method), or the circuit may be closed and opened for the sake of producing muscular contractions, or may be even reversed by means of a commutator, for the same purpose. These reversals are especially powerful in exciting muscular contraction.

Sometimes a bowl of water is useful as a medium between the electrode and the patient, who may dip a hand into the water in which one electrode is placed, and have the other electrode at the nape of the neck, or he may have two such bowls of water and put one extremity in each when the current is to traverse two limbs at once. Apparatus for treatment with a bath in which the electrodes are suspended is considered in §§ 69, 70.

When sensory impressions are chiefly desired the skin is treated dry with a metallic brush of very fine wires; a long secondary coil of many turns is most suitable for this purpose.

Generally speaking large currents are used when deep-seated parts are to be treated, and the electrodes must be large in proportion to avoid pain and injury to the skin.

The induction-current is to be employed where tonic or stimulating effects are chiefly desired, and with this object it is especially valuable in the treatment of paralysis. Where the involuntary muscles require stimulation the continuous current with interruptions and reversals is more effectual.

The continually expressed opinion that for muscles showing the reaction of degeneration the induction-coil is useless is a belief based more on theory than on practice. The everyday experience of those who are occupied with electro-therapeutics is completely against it. The results obtained by Duchenne from induction-coil currents are a sufficient testimony to the value of this mode of treatment in all kinds of paralytic affections.

It is true that a muscle showing the reaction of degeneration will contract to the constant current only, and in so far as the contraction of the muscle is a good thing for the muscle, the constant current may be better than that of the induction-coil ; but it is absurd to think that the amount of benefit can be measured by the amount of contraction set up in the muscle. A muscle which is completely and permanently cut off from its nucleus of origin will waste, however persistently it be made to contract by treatment with the constant current. This matter of the relative merits of constant and interrupted currents dates from a long way back. Each has been warmly advocated by its partisans to the exclusion of the other since the days of Duchenne and of Remak.

But in paralysis any form of electrical application is of value mainly, if not entirely, as a means of stimulating the activity of the living tissues of the part under treatment. With the constant current of a battery the stimulation is chiefly obtained when the current is made to vary, whether by interruptions or reversals, or by movements of the electrode over the surface, while with the coil the variations are produced in the apparatus. The action of electricity upon the growth of muscle is considered in § 184.

In paralyzed muscles it is often possible to notice the effects of fatigue after a very few contractions have been produced by electrical stimulation. Sometimes two or three closures of the testing key suffice to fatigue a damaged muscle so much that its contractions cease to be apparent. From this one may learn to adjust the strength of current and the duration of treatment for different cases. Very short applications are sufficient for muscles in a feeble state ; but they may be repeated at shorter intervals—say, twice or three times daily.

The number of applications necessary will vary very much, though usually a considerable number is required. In most electrical treatment a gradual slow improvement is all that can be expected. In some cases of infantile paralysis it may be necessary to continue treatment for several years. As a general rule it may be said that a month of treatment, with two or three applications a week, should be enough to produce signs of improvement, and in that case the patient will be encouraged to persevere. If at the end of a month of regular treatment there is no visible change, or if the improvement

has ceased to be progressive, then the treatment may be discontinued.

The following case illustrates the value of electrical treatment in a case of traumatic neuritis : A gentleman, by sitting for a long time in one position in an armchair, compressed the musculospiral nerve, and numbness and weakness of the hand, with wrist-drop, was produced. There was no treatment for several weeks, and there was no improvement. When seen he had paralysis with partial RD in all the extensors of the wrist and fingers ; the supinator longus was also paralyzed, and there was impaired sensation over the back of the forearm and hand. The nerve trunk was tender to pressure at a point about halfway up the humerus.

Electrical treatment was commenced, and at the end of a fortnight the patient had gained considerably in voluntary power, and appeared to be on the high-road to recovery. Electrical treatment was therefore suspended. He was instructed to rub the limb daily, and to exercise the muscles, and was told that he might expect the process of recovery to continue, even without further electrical treatment. A fortnight later he wrote saying that he had made no progress since the last electrical application. These were accordingly resumed, and improvement again began, and in another fortnight the patient was completely well.

The following instance of an Erb's paralysis is also instructive : A man fell into a ship's hold in January, 1898, and paralyzed the muscles of the upper arm. In the following year, March, 1899, he applied for relief, was seen and tested. A rupture of the fifth and sixth cervical cords of the brachial plexus was diagnosed, and an operation was performed for reunion. After the operation he disappeared from view for a time, and did not return until November. There was no recovery of power. The limb hung helpless from his shoulder. He was then tested electrically, and the examination showed a faint reaction of degeneration in the deltoid, biceps, and supinator longus. In the previous March, when tested before the operation, there were no reactions at all in these muscles. It was judged from the return of these faint reactions (RD) that reunion must have taken place after the operation, and electrical treatment was accordingly commenced. Improvement began immediately. After three months he had gained enough to be able

to use the limb for light work, and recovery went on steadily afterwards.

For those who are not unwilling to be convinced, these cases seem to offer satisfactory evidence that the electrical treatment played an important part in " curing " the paralysis, and answer the objection mentioned above, an objection which is not always easy to meet, because for obvious reasons it is difficult to combat it by direct proof.

All those who have had practical experience in the matter have seen cases of nerve injury begin to recover rapidly under electricity, after having been stationary for long periods of time under " expectant " treatment.

The cases of paralysis which follow injury to the nerve trunks are common, and are of interest from the exercise in applied anatomy which their diagnosis affords. The shoulder and upper limb are their most frequent seat. The chief causes of injury are contusions or lacerations, compression produced in various ways, and wounds with sharp instruments. Falls or blows upon the shoulder and dislocations of the shoulder-joint commonly produce paralysis of the muscles of that region. Pressure, as from the use of crutches, or from the weight of the body upon the arm during sleep, often produces paralysis of the muscles supplied by the musculo-spiral nerve, and incised wounds of the forearm and wrist often lead to paralysis of the muscles supplied by the ulnar and median nerves. In all cases of this kind favourable results may be expected unless the nerve trunks have been actually severed, or are involved in cicatricial tissue. In that case surgical measures to unite the ends of the divided nerve, or to relieve it from its surroundings, are necessary before recovery can be expected.

From what has been said in § 221 it follows that injuries of nerves are likely to be followed by a reaction of degeneration in the muscles which they supply, and this does always follow if the injury to the nerve has been sufficiently severe. But as such injuries may be of any degree of severity, it will be found that the reaction of degeneration is not invariably produced, for in the slighter cases the injury may be sufficient to impair motor and sensory conduction for a time without interfering with what may be called the trophic conduction of the nerve trunk. The partial reaction of degeneration is not uncommon in cases of nerve-trunk injury.

233. **Applications of Electrical Treatment.**—It is a matter of importance that all but the simplest forms of electrical treatment should be carried out by the medical man himself wherever this is possible, and if it is not possible for him to do so, then at least he should supervise the treatment as often as he can. When the expense of electrical treatment applied daily for long periods by a medical man may prevent the patient from giving the treatment a fair and prolonged trial, it may sometimes be desirable to teach the patient or a relative or a nurse what to do. This is particularly the case in chronic conditions, where the necessary manipulations are simple, and where a successful result from the electrical treatment cannot be predicted with certainty, The aid of electro-therapeutic methods is often invoked only when every other treatment has been tried without success, and thus it happens that many cases have already become chronic and difficult to influence before they come for electrical treatment. Moreover, the mode of action of electricity upon the tissues of the body is in its essence a gradual one, working as it does by a slow rebuilding or regeneration of the damaged organ or function, and requiring time and the exercise of patience and perseverance in its applications. It is among the poor in hospital practice that one has the best opportunities of seeing the good which can be done by electrical treatment in chronic cases. In that class of patient considerations of expense do not interfere to cut short the treatment prematurely, nor are hospital patients so ready to throw up one kind of treatment in order to try something different. Thus it is a not uncommon experience to have similar cases under treatment at the same time, the one at the hospital and the other as a private patient, and to see the latter throw up the treatment when half through with it, while the former goes steadily on and makes a good recovery.

Whenever the treatment must be carried out by a nurse, she must be given a few careful lessons in the anatomy of the part to be treated, and in the manipulations to be performed at the commencement of the case. She must be supervised at frequent intervals by the medical man in charge of the patient, who should never omit to make measurements and tests from time to time to ascertain what progress is being made, and to prevent the case from being left in the sole charge of the nurse.

234. **The Ocular Muscles.**—Their deep-seated position, the proximity of the retina, and the sensitiveness of the conjunctiva all help to make it practically impossible to excite contractions in these muscles by electrical applications, except in the levator palpebræ, in which a "longitudinal" reaction of degeneration has been observed. Good results have sometimes appeared to follow treatment by means of direct currents applied longitudinally through the skull, the kathode being placed upon the closed eyelid. Dr. Buzzard has recommended the use of the operator's index finger as the active electrode. Small sponges may also be used, as they are soft and readily adapt themselves to the surface of the eyelid. Dr. Buzzard has reported two cases where improvement followed the use of the direct current. Owing to the difficulties of satisfactory application, electricity is not of much use in the treatment of ocular paralyses.

235. **Facial Paralysis.**—This form of paralysis very frequently comes under electrical treatment.

Paralysis of the facial muscles may be the result of cerebral disease, as in hemiplegia, cerebral tumour or meningitis, but its most common cause is disease of the nerve trunk itself, and the part of the nerve which is usually at fault is that which passes along the Fallopian aqueduct.

In this part of its course a slight amount of swelling of the sheath of the nerve, or of the lining of the bony canal, is sufficient to produce compression of the nerve fibres, and consequently a paralysis of the facial muscles. This is the generally accepted explanation of the fact that facial paralysis is frequently seen in persons who are otherwise in good health. In many of these cases the onset of the paralysis can be attributed to some definite exposure to cold, and especially to a cold draught of air blowing upon the cheek, but in many others the history is by no means conclusive in this respect. A "rheumatic" tendency has been assumed as a predisposing cause. The common occurrence of facial paralysis is probably associated with this anatomical peculiarity of its course through a narrow bony canal, as any compression produced by congestion at that part of its course is likely, when once started, to lead to greater congestion for mechanical reasons.

As the severity of the paralysis in these cases will depend upon the length of time during which the nerve fibres are compressed, it is very important to endeavour to reduce congestion

as early as possible. The application of blisters or leeches should always be attended to in cases of facial paralysis if they are seen soon after the onset.

Facial paralysis is often associated with disease of the ear, and is then due to an extension of the inflammatory process to the Fallopian canal, or to the facial nerve itself. It may also be caused at birth by pressure of the obstetrical forceps upon the nerve after its emergence from the bone.

The reaction of degeneration, complete or partial, is present in a large proportion of cases of facial paralysis. Normal reactions may remain in mild cases. Sometimes it happens that the reactions of the upper part of the face may differ from those in the lower part, showing an unequal degree of damage to the respective groups of nerve fibres. If the patient is tested daily from the commencement the gradual development of the RD will be clearly seen. As the reaction to the induction coil current may not disappear until the lapse of seven or ten days from the time of onset, a favourable prognosis cannot safely be given from a test made within that time. In testing a case of facial paralysis, it is well to bear in mind that the skin of the face is sensitive, and that the muscles are near the surface; strong currents are therefore unnecessary, and must be avoided. Old patients do not do so well as younger people. A considerable proportion of cases of facial paralysis occurs in young women; they are excellent examples for study, as they attend with the greatest diligence until completely recovered.

If a case of simple facial paralysis receives no electrical treatment, its rate of recovery will be slower than if it be so treated. The cases of facial paralysis from ear or bone disease are naturally more unfavourable than those coming on from "cold." The hemiplegic cases usually recover fairly without treatment. Care must be taken to exclude all likelihood of the existence of unfavourable causes of the paralysis before making a favourable prognosis. All cases presenting unusual features are to be regarded with suspicion. Facial paralysis from disease of the motor nucleus of the nerve may occur.

The electrical treatment should be in accordance with what has been laid down for paralysis in general—viz., direct treatment of the affected nerve and muscles, and reflex stimulation through the sensory nerves of the skin of the face. For cases showing the reaction of degeneration both the direct and the

interrupted current should be used. The indifferent positive electrode should be placed at the back of the neck, and the active electrode applied to the nerve and the muscles, each of the main branches of the nerves being followed in a labile manner from centre to periphery, and each muscle being treated with a few interruptions with the help of the closing key. Lastly, the skin of the face and the muscles may be treated with the induction coil. If normal reactions have not been lost, treatment with induction coil currents will be all that is required. A metal-mounted brush of bristles can be converted into an electrode, and makes an agreeable instrument for applications to the face.

It has been proposed by Ballance and Stewart to remedy the deformity produced by permanent facial paralysis by an operation to connect the peripheral part of the facial nerve to a strand taken from the hypoglossal or spinal accessory.*

A "secondary contraction" of the facial muscles is often seen in cases of facial paralysis. Usually it shows itself during the course of recovery in the more serious cases. There may be a tonic contraction which shows itself in a narrowing of the palpebral opening on the affected side, or in a drawing of the angle of the mouth to the affected side, or there may be occasional twitchings in some of the affected muscles. Again, there may be an associated action in the muscles, so that movements of the eyelids occur when the muscles of the lips are set in action, and, conversely, the mouth may move when the eyes are closed. This secondary contraction in the muscles of the face has nothing in common with the "late rigidity" which appears in the limbs in cases of hemiplegia. It is the result of the original mischief which has caused the facial paralysis in the first instance. If this is only in part removed, its presence may act as a source of irritation to the nerve, and thus cause the tendency to spasm.

236. **The Tongue and Soft Palate.**—Paralysis of the muscles of mastication is very rare. Injury or disease of the hypoglossal nerve may cause paralysis of the muscles of the tongue. Atrophy of one side of the tongue and a reaction of degeneration have been observed. The soft palate is occasionally paralyzed, and its muscles may show a reaction of degeneration. If it should be required to test any of these muscles, a small electrode should

* *British Medical Journal*, May 2, 1903.

be used ; it may be covered by a layer of moist absorbent cotton, or it may be used uncovered.

237. **The Trapezius and Sterno-mastoid.**—Paralysis and atrophy of these muscles follow injury or disease of the spinal accessory nerve, or of its nucleus. The trapezius, and sometimes the sterno-mastoid muscle as well, may suffer as a result of the suppuration of strumous glands in the neck, or of the surgical operations for their removal.

Paralysis of the sterno-mastoid is easily recognised if looked for. When the head is turned towards the opposite side, the

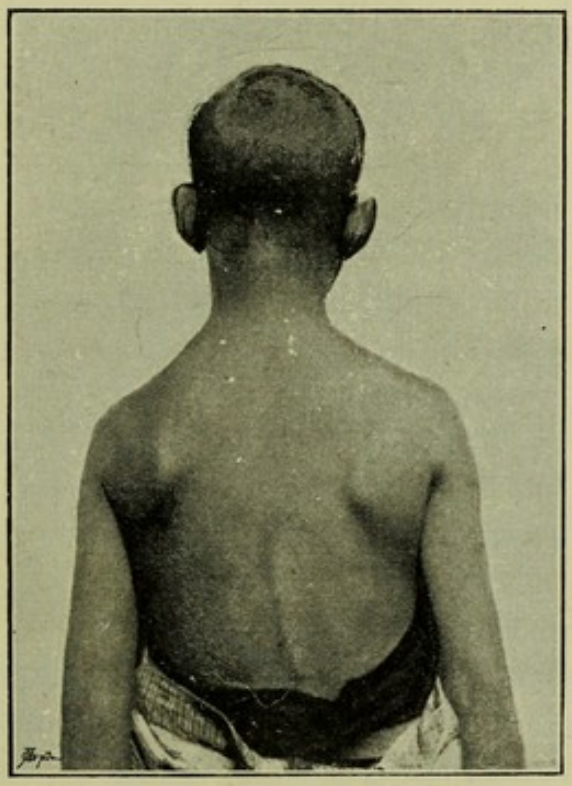


FIG. 175.—PARALYSIS OF LEFT TRAPEZIUS.

outline of the muscle standing out under the skin is plain to see in health, but is lost if the muscle is paralyzed.

When the trapezius is paralyzed there is a general feeling of weakness, and a complaint of myalgic pains about the shoulder, because the muscle plays so large a part in supporting the shoulder during the movements of the upper limb.

When one trapezius is paralyzed the difference between the two shoulders can easily be recognised, particularly if the muscle be wasted as well. On the affected side the whole of the shoulder is lowered, and the line from the neck to the shoulder-tip is flattened. This difference is best seen with the arms hanging at the sides (Fig. 175). The position of the scapula is changed

and the inner border of the bone does not lie parallel to the vertebral column, as in health, but at an angle with it, its upper corner being rather further from the middle line, and its lower angle nearer, at a higher level, and more prominent. Duchenne has explained why this is the case. The shoulder, having lost the support of the upper part of the trapezius, hangs suspended from the levator anguli scapulæ, and turning as on a pivot, at the point of attachment of that muscle, its lower angle is tilted

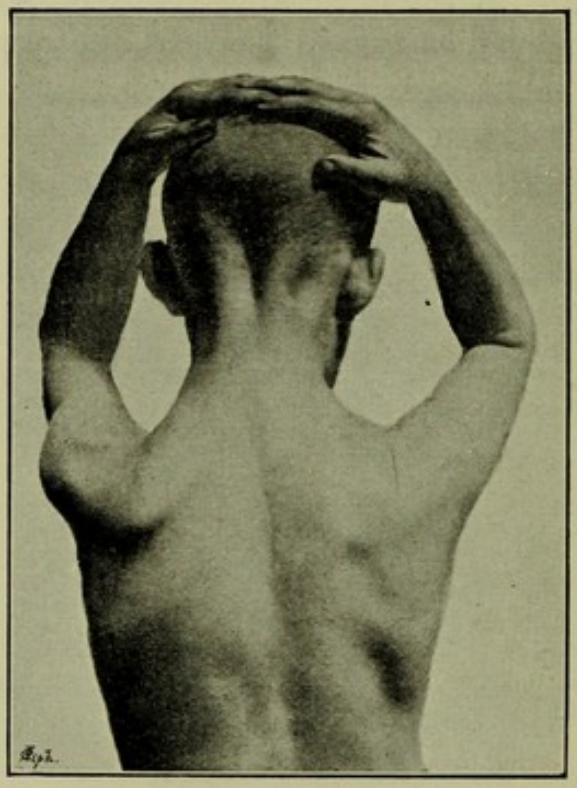


FIG. 176.—PARALYSIS OF LEFT TRAPEZIUS.

Clavicle seen from behind.

inwards and upwards, and the acromion sinks downwards by the weight of the arm.

If the patient raises the arms to the head another peculiar defect comes into notice—namely, that the clavicle in its outer half comes into view from behind. This is a valuable diagnostic sign of atrophy of the muscle (Fig. 176).

Paralysis of the trapezius is often due to injury of the spinal accessory nerve during surgical operations on the neck. In one such case the incision was a small one, at the posterior border of the upper part of the sterno-mastoid. The nerve was accidentally divided, and the muscle became wasted, especially in its upper and middle portions. The clavicular part—the *ultimum*

moriens of Duchenne—as well as the rest of the muscle, showed a marked reaction of degeneration. The lower part of the muscle was not quite so much affected as the upper part, and the inferior angle of the scapula was therefore pulled downwards and not tilted upwards, as is the case when the whole muscle is paralyzed. In another case the whole of the side of the neck was much scarred, as the result of numerous strumous abscesses and of the surgical treatment for their relief. Both the trapezius and sterno-mastoid on the right side were extremely wasted.

The results of treatment in cases of paralysis of the sterno-mastoid and trapezius will depend upon the nature of the nerve injury. Where the nerve has been divided, and scar tissue is left surrounding the divided ends, the chances of a spontaneous reunion of the nerve are very small, and a surgical operation for the restoration of continuity in the divided nerve should be tried.

Recovery has gradually appeared in some cases where there has been reason to believe that the nerve was divided, and in such cases it is probably due to regeneration of the nerve at its divided part. Electrical treatment should be energetically applied if there are reasons for hoping that the nerve is not completely divided, or if there are signs of returning power. In the other cases a surgical operation should be recommended.

238. **The Serratus Magnus.**—Paralysis of this muscle is interesting, because the deformity which results from it is peculiar. The serratus magnus is supplied by the posterior thoracic nerve, which rises from the fifth, sixth, and seventh cervical cords, and runs down the side of the chest behind the brachial plexus to reach the muscle. In the first part of its course the nerve runs in the substance of the scalenus medius muscle. The position of the nerve makes it liable to injury, especially in the side of the neck, and its independent course may explain the reason why paralysis of the serratus magnus is frequently seen without any other muscle being affected at the same time. Occasionally the nerve to the rhomboids comes off as a branch from the first part of the nerve to the serratus, and therefore the rhomboids may be paralyzed with the serratus magnus.

The peculiar deformity which characterizes paralysis of the serratus magnus is easily recognised if looked for. When the patient is examined with the arms hanging down the shoulder may seem natural, but when the patient attempts to extend the

arms horizontally in front of him the movement is performed imperfectly, and the posterior border of the scapula on the affected side becomes prominent, projecting like a ridge from the level of the back (Fig. 177). In a healthy person the scapula remains applied to the thorax during this movement; the function of the serratus magnus is to hold the scapula closely to the side of the thorax, and to advance it towards the front. When the arms are extended in front, the action of the deltoid tends at the same time to throw the scapula backwards, and this is resisted by the simultaneous contraction of the

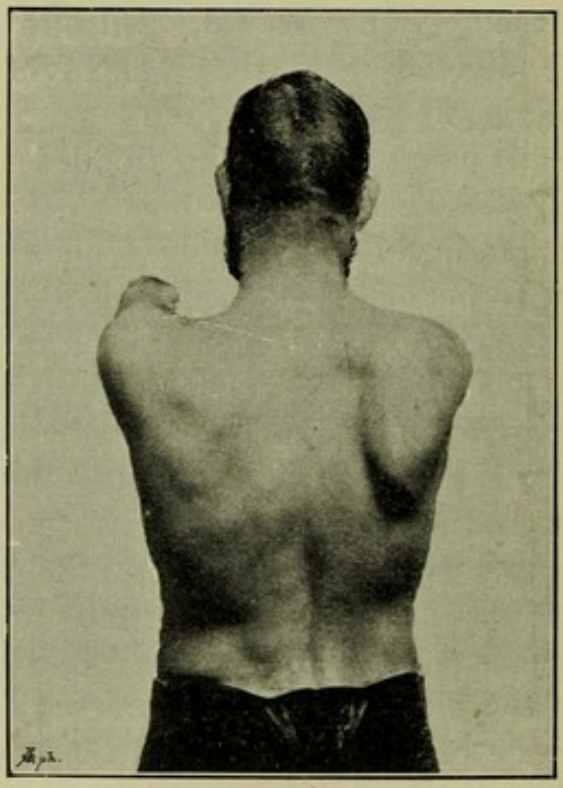


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FIG. 177.—PARALYSIS OF RIGHT SERRATUS MAGNUS.

serratus magnus. If the deltoid be paralyzed as well as the serratus, the patient cannot extend his arm horizontally, and the deformity due to the paralysis of the serratus cannot be brought out in the way just mentioned. In this case, if the shoulder be pushed back while the patient is told to resist, it may be found that the posterior border of the scapula can be more easily displaced on the side of the paralysis.

Paralysis of the serratus magnus is not uncommon as a result of direct injury to the nerve in the side of the neck. The following example will serve as an illustration of the usual history of such cases: A man was using an iron bar as a lever

to move heavy weights along the ground, which he did by putting the end of the bar on his shoulder, and pushing upwards forcibly against it ; he felt a pain, and soon afterwards he found that his shoulder began to 'grow out.' When he came under observation there was marked paralysis of the right serratus magnus, and the rhomboids were also affected, which made the characteristic deformity of the shoulder even more pronounced.

Paralysis of the serratus magnus may occur as part of an extensive injury to the region of the shoulder. In two cases of which I have notes the patients had suffered severe injuries, one having been crushed in a lift accident, in which he broke his forearm, and the other having been hurt by a heavy packing-case, which fell upon him. Both of these, in addition to other injuries, had paralysis of one serratus magnus—the right. Indeed, all the cases of paralysis of the serratus magnus from injury which I have seen have been on the right side, and in male patients.

Paralysis of the serratus magnus is by no means uncommon as a result of neuritis, quite apart from injury. Cases have been recorded after many of the specific fevers, and the figure shows a case in which it came on after an illness, presumably of a septic nature. An instance in which this form of paralysis followed small-pox is described and well figured in the *Journal of the Royal Army Medical Corps*, April, 1904.

Cases due to injury or disease respond well to electrical treatment, unless the nerve is actually divided ; division of the nerve is not often met with.

In testing and treatment the indifferent electrode is placed in the posterior triangle of the neck, and the active electrode is applied to the serrations of the muscle.

The notion is sometimes entertained that the peculiar position of the shoulder-blade, described above, is due to dislocation of the latissimus dorsi from its position at the angle of the scapula. This view is erroneous.

239. **The Scapular Muscles.**—The supra- and infra-spinati are often paralyzed as the result of blows upon the shoulder, though less frequently than the deltoid.

When the spinati are wasted, the spine of the scapula becomes prominent, and the muscles themselves can be seen to be diminished in bulk. The patient is unable to perform external rotation of the humerus in a proper manner if the infra-spinatus

is paralyzed, and the other external rotator of the humerus, the teres minor, is often affected simultaneously, though supplied by a different nerve. The movement of external rotation is necessary in writing for moving the hand across the paper, and in sewing the same muscles also come into play.

The nerve (supra-scapular nerve) which supplies the spinati is exposed to the risk of injury, owing to its superficial position on the shoulder. The supra-spinatus is a less important muscle than the infra-spinatus, and its condition is not so easy to determine, because it is thickly covered by the trapezius, which makes electrical testing of the muscle difficult, and its functions as an elevator and a weak internal rotator of the humerus can be performed by the deltoid. When the infra-spinatus is paralyzed it is probable that the supra-spinatus is in the same condition.

The internal rotators of the humerus—namely, the subscapularis and teres major—have a nerve supply (the subscapular nerves), which escapes injury much more often than the spinati ; and the same may be said of the latissimus dorsi, which is also supplied by a branch from the brachial plexus—viz., the long subscapular. The pectoralis major and minor also escape, as a rule.

There is no special point to note in the electrical testing and treatment of these muscles. Usually they are affected with the deltoid, and their treatment is similar to that which is employed for the latter.

240. **The Deltoid.**—Paralysis of this muscle from blows upon the shoulder or dislocation of the shoulder-joint is one of the most common forms of paralysis in the upper extremity.

The circumflex nerve is exposed to injury in its course through the muscle, and its trunk may also be strained in dislocations, or it may be compressed by a crutch or axillary pad. The teres minor suffers with the deltoid when the injury is to the trunk of the nerve ; when the injury is in the intramuscular part it may escape. It is not always easy to determine the state of the teres minor by electrical testing, as it is so much covered by other muscles, nor by observing the voluntary movements of the patient, as its functions can be adequately performed by the infra-spinatus. The attempt to ascertain its condition, however, should always be made.

The spinati are often paralyzed by the injury which paralyzes the deltoid.

The flattened appearance of the shoulder and the prominence of the acromial process of the scapula make it easy to recognise paralysis of the deltoid unless the subject be very stout. In infants especially the adipose tissue which covers the shoulder may mask the wasting of the muscle. When the wasting and paralysis are extreme the head of the humerus is no longer held up in the glenoid cavity, but can be seen and felt to hang loosely in a state of partial dislocation, and to be freely movable in its socket. One may even be able to push the tip of a finger between the acromion and the head of the humerus.

When the deltoid is paralyzed the arm cannot be raised to the horizontal position, and the utility of the limb is very seriously diminished for a very large number of movements, as no other muscle is able to supplement its action to any appreciable extent. The supra-spinatus, which has a similar function, is too feeble to be able to raise the weight of the arm. It sometimes happens that part only of the deltoid is paralyzed ; I have notes of three cases. In one the patient had had suppuration round the shoulder, and an incision for the evacuation of the pus was made on the posterior aspect of the joint. One of the branches of the circumflex nerve was injured, and the posterior half of the muscle was wasted, and showed a partial reaction of degeneration, while the anterior part reacted naturally.

Traumatic paralysis of the deltoid is very common. Recovery is the rule in the majority of the cases, but there is a considerable minority which do not improve at all satisfactorily, and on this account it is wise to express a guarded opinion when there is much wasting and a reaction of degeneration, and the prognosis must be made to depend upon the behaviour of the muscle under treatment. In elderly people particularly the progress of recovery is very slow, and six months or more may pass before much improvement is visible. If the electrical reactions are normal, or show only a quantitative change, or show the partial reaction of degeneration, with some preservation of induction-coil reactions, the prognosis is more favourable. Taken generally, the deltoid may be said to be a muscle which is easily damaged, and has not a very great recuperative power. The presence of articular changes in a case of paralysis of the deltoid is very common, as both muscle and joint are supplied by the circumflex nerve, and both suffer when the nerve is injured. Adhesions in the joint should be treated by mechanical means

after the nerve has recovered its functions. If the adhesions are broken down before the muscle and nerve are restored they are very likely to form afresh. The skin over the deltoid receives sensory fibres from the circumflex nerve, and loss or impairment of sensation is frequently to be found if looked for when the muscle is paralyzed.

241. **Combined Paralyses of the Upper Limb.**—It may happen that muscles supplied by more than one nerve trunk may be paralyzed together from injury or disease. After dislocation of the shoulder, and particularly when a dislocation has remained for some time unreduced, there may be complete paralysis of the whole limb.

Several causes combine to produce extensive paralysis after a dislocation. In dislocations forward the head of the humerus presses upon the brachial plexus below the coracoid process, and so produces paralysis below that point ; but this pressure will not cause paralysis of the muscles of the scapula, for these are supplied by branches given off higher up, and yet they are generally, if not always, implicated. It is said that the upper cords of the plexus may be compressed between the clavicle and the vertebral column if the violence has tended to drive the shoulder backwards, for the shoulder has free play at the sterno-clavicular joint, and might be driven sufficiently far back to produce such compression. The upper cords of the plexus may be directly subjected to traction from the injury, or finally they may be damaged by the efforts employed in reducing the dislocation.

It seems probable that the commonest cause of injury to the upper cords of the plexus is a stretching force acting either at the time of the injury or in the efforts to reduce the dislocation, while the muscles of the forearm and hand are paralyzed from the pressure of the dislocated head of the bone upon the lower cords subsequently. Severe injury to the shoulder may cause rupture of the nerve roots which form the brachial plexus. When the spinal nerve-roots are torn there may be laceration of the fibres which emerge from the thoracic cord to supply the cervical sympathetic, and the pupil on the injured side may be contracted in consequence. A. A. Bowlby* has published some cases in which this has been observed.

It happens sometimes in cases of severe injury to nerve trunks

* "Injuries and Diseases of Nerves," London, 1889, J. and A. Churchill.

that the paralyzed muscles become hard and inelastic, and to the touch feel almost 'wooden.' This condition contrasts strongly with the flaccidity of ordinary paralyzed muscles. It is probably an effect of interstitial œdema, and signifies very serious damage. No reaction can be got from muscles in this condition, but an RD may be seen in them later, when the hardness has passed away.

244. **Root Paralyses—Erb's Paralysis.**—Paralysis of muscles caused by injury or disease of the roots of the brachial plexus has been called "radicular paralysis" or "root paralysis." The grouping of the affected muscles in "root paralysis" will depend upon the representation of the muscles in the different spinal nerve roots which go to make up the brachial plexus, and will not correspond with the grouping according to nerve-trunk distribution. It is evident that electrical testing may be of prime importance in distinguishing between paralysis due to nerve-trunk lesions and those caused by lesions of the nerve roots.

One particular type of root paralysis affecting the muscles of the shoulder and arm has received the name of Erb's paralysis, though in France it is often known as the Duchenne-Erb type, because Duchenne first drew attention to it in 1867, and reported five examples. It was Erb who, in 1874, pointed out the anatomical reasons for the special grouping of the paralyzed parts. Erb enumerates the affected muscles as the biceps, coraco-brachialis, and brachialis anticus, which are supplied by the musculo-cutaneous nerve; the deltoid, supplied by the circumflex nerve; and one muscle supplied by the musculo-spiral, namely, the supinator longus; sometimes the spinati too (supra-scapular nerve) are involved. The affection of the supinator longus alone among the muscles supplied by the musculo-spiral nerve might seem at first to be a perplexing feature, but it is easily explained on the ground that the injury is situated above the point at which the musculo-spiral nerve is built up. Compare the condition in wrist-drop from lead, in which the supinator longus may escape when the rest of the muscles supplied by the musculo-spiral nerve are paralyzed. Erb pointed out that an injury limited to the two upper roots of the brachial plexus, the fifth and sixth cervical, or their combined trunk, would produce the kind of paralysis under consideration; and further showed that these cords can be directly stimulated at a point in the neck one inch above the clavicle

and a little external to the outer border of the sterno-mastoid. This is known as Erb's motor-point, and by means of an electrode applied to it, the group of muscles in question can be readily thrown into simultaneous contraction.

The existence of Erb's paralysis as a clinical unit depends upon the comparatively exposed position of these two nerve roots, just as we have seen that paralysis of some of the single muscles of the shoulder are common for the same reason, and varieties in the extent of the paralysis exist according as the injury or disease affects chiefly the fifth or the sixth roots or their united trunk, or extends into the seventh.

From what is known one would expect that a lesion of the fifth and sixth roots, or of their combined trunk, should involve not only the muscles already mentioned, but also the rhomboids, the teres minor, the subclavius, and the upper parts of the pectoralis major and serratus magnus, and the supinator brevis, and most of these muscles have been noted as involved in some of the recorded cases. When they escape it must be due to their partial representation in one or more of the other nerve roots of the brachial plexus.*

It must be borne in mind that Erb's paralysis is not a special form of disease. The name signifies the paralysis of a special group of muscles. Any sort of injury or disease which affects this special part of the brachial plexus will produce paralysis of the group of shoulder and arm muscles already mentioned. Traction on the arm of a child during difficult labour is a common cause of Erb's paralysis, so that Duchenne described it as "obstetrical" palsy of the arm. Among twenty cases of which I have notes, seven were caused in this way, four followed direct injury, one was due to sarcoma of the cervical vertebræ; but, from the extension of the disease, the paralysis was not long limited to the muscles of the Duchenne-Erb group. One was associated with an abscess in the neck, and the remainder came on gradually, and were due to neuritis of some kind.

All degrees of combined paralysis, from the typical Duchenne-Erb type to complete paralysis of the shoulder and arm, may be met with.

The triceps in some cases and the extensors of the wrist in others have been noted to be weak in cases of Erb's paralysis.

* For much important work upon these and associated matters, see Sherrington, "The Spinal Animal." *Medical Chirurgical Transactions*, 1899.

In two cases I have noted some weakness of the upper part of the pectoralis major.

Wilfred Harris and Warren Low believe that the characteristic lesion of Erb's paralysis is situated in the fifth cervical root, and not in the common cord formed by the junction of the fifth and sixth, and they further state that they have found the pronator radii teres and the radial extensors of the wrist to be involved in association with the other muscles generally affected in Erb's group.

There is a certain amount of variation between individual cases, so that we cannot state absolutely that certain fibres run always in the fifth root, and certain others only in the sixth or seventh. Moreover many or most of the limb muscles receive their nerve supply by roots emerging at more than one level; for example, the serratus magnus from the fifth, sixth, and seventh cervical roots.

243. **The Muscles of the Arm and Forearm.**—The musculo-spiral, the median, and the ulnar nerves are often injured in their course in the arm and forearm. The usual causes are incised wounds, implication in callus or scar tissue, contusions, pressure from bandages or splints too tightly applied, or pressure from the use of crutches, or from lying or sleeping with the weight of the body resting upon the limb. Pressure palsies affect more especially the musculo-spiral in the upper arm; while the ulnar and median suffer more particularly from incised wounds, and in the forearm. In all cases of paralysis affecting the upper limb it is important to make a careful test of the reactions of the muscles, in order to determine the situation of the lesion, its severity, and, above all, to ascertain whether a nerve is likely to have been severed or not. If it is severed the question of an operation for reunion of the divided ends must be considered. Paralysis from the pressure of splints and bandages is sufficiently common to be of importance, and though, fortunately, it is not usual for injury produced in this way to cause permanent harm, yet sometimes it does do so. I have notes of many cases in which there was little or no doubt that tight bandaging had caused paralysis. Thus, in one patient who received an incised wound involving the median and ulnar trunks, it was found, when the wound had healed, that he had developed a paralysis of the musculo-spiral as well. Paralysis from tight bandaging is seen with especial frequency among persons who

have received injuries when far away from skilled assistance, and have had their injuries bound up tightly and left so until medical assistance could be reached.

In all cases of injury to nerves, except when the nerve is severed, electricity should be used for purposes of treatment. Arm-bath methods (§ 154) are of great convenience for injuries at or below the elbow, but good results are also obtained by direct applications. The coil or sinusoidal current may always be used, and in cases with RD the battery current should be used to supplement it.

244. **The Musculo-spiral Nerve.** — Paralysis of the muscles supplied by this nerve is characterized by the presence of wrist-drop. Usually the extensors of the wrist and fingers and the supinator longus and brevis are involved; the triceps may either escape or may be implicated, according as the injury is high up in the arm or not.

Musculo-spiral paralysis from pressure on the trunk of the nerve during sleep is extremely common—at least, among hospital patients.

The usual history is that the patient goes off into a heavy sleep, from which he awakes with his hand and forearm powerless. Often the patient has slept while sitting at a table with the head resting on the arm, or with the arm hanging over the back of a chair; in either case the musculo-spiral nerve trunk has been pressed upon. It does not often follow sleep in bed. Almost always the patient has been under the influence of alcohol and has slept very soundly. Otherwise the discomfort felt in the arm would have been likely to awaken him before the production of more than a transient paralysis. Nearly all the cases are in intemperate persons. The predisposing effect of intemperance is well shown in the following case: A potman, after sleeping for two or three hours, developed a pressure palsy of his left musculo-spiral nerve. This got better, but in the following year he injured his ankle, and was obliged to use a crutch. This brought on another attack of musculo-spiral palsy before he had used the crutch more than ten days.

Slight degrees of temporary paralysis from pressure on a nerve-trunk during sleep are familiar to most persons. To notice a numbness or a feeling of pins and needles in one arm on awakening from sleep is not uncommon, especially among those who are in a poor state of health.

Pressure paralysis has been thought to be secondary to compression of the bloodvessels of the limb, producing anæmia of the nerve; but if this were the case the paralysis should not be confined to the region of one particular nerve trunk, as is the rule if it were due simply to anæmia of the limb from compression of the main artery. It would rather be expected to involve chiefly the distal parts, irrespective of the nerve supply.

A case of a pressure palsy in the leg, which came under my observation some years ago, shows that it is the nerve itself which suffers from compression. In that case the pressure was on the great sciatic nerve at the back of the thigh, and there could not have been any compression of the femoral artery. The patient was a young man who attended a meeting, and in order to have a better view of the proceedings, he sat for an hour upon the back rail of his chair; at the close of the meeting he found his leg numb and helpless, and was assisted home. Two days later he came under observation. He had paralysis of all the muscles below the knee. He recovered in a fortnight under treatment by rubbing and the induction-coil current.

Sleep palsies are almost always limited to the musculo-spira nerve.

In crutch palsy, too, it is usually the musculo-spiral nerve alone which is paralyzed, but the circumflex nerve or the ulnar or median may also be involved. Sleep palsies are always unilateral; crutch palsies may be double if two crutches are used; they are usually more marked on the side of the injured leg.

The degree of impairment of sensation varies much; as a rule, there is some complaint of numbness on the back of the forearm and hand, and some anæsthesia may be detected.

Paralysis of the extensor group from lead-poisoning is frequently met with. Fractures of the humerus may cause extensor paralysis from injury to the trunk of the musculo-spiral nerve by the broken bone, or the nerve may be implicated in the callus thrown out around the fractured points.

A rare form of extensor paralysis is one which affects the special extensors of the thumb. I have twice seen a paralysis of these muscles alone with a reaction of degeneration in cases without any history of previous injury.

All these forms of extensor paralysis vary considerably in severity. Those in which the electrical reactions are not much impaired may recover in ten days or a fortnight. When the

reaction of degeneration is present the duration will be longer, and may last for more than three months. Recovery can be confidently expected in uncomplicated cases, where the pressure has not lasted very long, and it is certainly promoted by electrical treatment. I have often seen improvement start at once on the commencement of electrical treatment, after weeks had been wasted in vain in the expectation of spontaneous recovery. It is probable, however, that even in these the paralysis would go away of itself in time, but this does not prove that electrical treatment is unnecessary.

When the pressure is due to the use of crutches they must either be given up, or, if that is impossible, the head of the crutch must be well padded, and the state of affairs must be explained to the patient, so that he may be able to co-operate. Crutches with handles which can be grasped in the hands are the best, for with them the patient can transfer part of his weight from the armpits to the wrists. The crutches should be attended to before they have produced paralysis. The sensory loss after division of the musculo-spiral nerve is difficult to describe, and for information the student should consult Sherren's paper.*

245. **The Ulnar and Median Nerves.**—These nerves are frequently divided at or near the wrist by incised wounds, a very large number of the cases being from cuts caused by broken glass. It is not uncommon for both nerves to be divided in one accident, and if the ends are not reunited when the wound is first dressed, wasting and paralysis of all the intrinsic muscles of the hand is the result. The nerve may also be injured at the elbow, and cases have been recorded in which a fracture of the internal condyle of the humerus has been followed some years afterwards by interference with the functions of the nerves.

When the ulnar nerve has been completely divided near the wrist the symptoms produced are: Paralysis, with wasting and the reaction of degeneration in the hypothenar eminence, in all the interossei, in the two ulnar lumbricales, and in the adductor and flexor brevis (inner head) of the thumb. After a time the deformity known as the "clawed hand" is produced. The palm becomes thin and flat, the heads of the metacarpal bones and the flexor tendons in the palm become unduly

* J. Sherren, "The Distribution and Recovery of Peripheral Nerves," *Lancet*, March 17, 1906.

prominent, the proximal phalanges are over-extended, the distal phalanges are permanently flexed. This is the result of the paralysis of the interossei. These muscles flex the proximal phalanges and extend the distal ones, and so balance the movements of the fingers, which are performed by the long flexors and extensors. If the interossei are paralyzed, the unbalanced action of the long extensors and long flexors produce the characteristic deformity.

The ulnar nerve supplies with sensibility to light touch one and a half fingers, and the corresponding portion of the palm and dorsum of the hand. With sensibility to prick exclusively and in common with other nerves, the little and ring fingers, the palm, with the exception of the thenar eminence, and on the dorsum that portion of the hand to the ulnar side of a line drawn through the axis of the middle finger. In division of the nerve, sensibility to light touch is lost over both surfaces of the little and half the ring fingers, with a corresponding portion of the palm and dorsum of the hand. This area is liable to very little variation. An area insensitive to prick is present over the little finger back and front, and a portion of the ulnar palm varying from a strip on its extreme border to an area almost as extensive as that of the loss of light touch (Sherren).

After division of the median nerve at the wrist the conditions are different; the clawed hand, which is so characteristic of the divided ulnar nerve, is not present, and the chief feature is the wasting of the thenar eminence and the everted or ape-like thumb, which lies with the nail facing dorsally; the abductor, opponens, and outer head of the flexor brevis of the thumb are paralyzed, atrophied, and show the reaction of degeneration.

Sherren, in summing up the sensory supply of the median nerve, states that it supplies sensibility to prick, partly exclusively and partly in common with other nerves, to the whole of the palm, with the exception of a narrow strip along its ulnar border. On the dorsum it supplies the whole of the dorsal surface of the index, middle fingers, and in most cases the ring finger and the terminal phalanx of the thumb. It as often happens in many of the injuries in the neighbourhood of the wrist tendons are divided in addition to the nerve. This usually results in the appearance of an area insensitive to deep touch almost as extensive as that of loss of sensibility to prick.

246. **Paralysis of First Dorsal Root.**—The cases described by

Lewis Jones* of atrophy of the intrinsics of the hands in young persons may be assigned a position as cases of root paralysis from disease of the first dorsal spinal root. The characteristics of this group of cases are well marked. They usually show atrophy of the intrinsics of one or both hands; the median and ulnar muscles are affected together, although the muscles in the forearms supplied by these nerves may escape. The wasting is usually greatest in the ball of the thumb, and a reaction of degeneration is often present. Pain, if complained of, is not severe, and is referred to the area corresponding to the first dorsal sensory root, as has been pointed out by E. F. Buzzard,† who has described some cases of the same character. Many of these hand atrophies are due to the presence of a cervical supernumerary rib, which may exercise pressure upon the first dorsal root, and is especially likely to do so if the root passes upwards over the cervical rib, as has been observed to occur in several cases. Dr. W. Thorburn‡ first suggested that the existence of a supernumerary rib as a cause for this form of paralysis was probable, and he showed X-ray photographs of two examples.

247. **The Lower Limb.** — Cases of paralysis from disease or injury of the nerves of the lower limb are much less common than they are in the arm. I have notes of only a few instances. In one recorded case there was paralysis of the front leg muscles from the pressure of a leather pad upon the peroneal nerve just below the head of the fibula. The patient was a man who walked daily upon stilts, which were strapped tightly round the legs just below the knee, and so set up the pressure upon the nerve.

Other cases may follow injury about the knee-joint, gunshot wounds of the thigh, or fractures through the lower third of the femur, and the operation for the relief of genu valgum may cause injury to the nerve trunks. The most usual seat of the injury to the nerve trunks of the lower extremity is in the external popliteal nerve or the peroneal nerve. This was the case in the following instance: The pressure occurred during occupation. In one, a carpenter sat on the ground with one leg doubled under him; in the other, a leather-sewer fixed her work

* 'On Symmetrical Atrophy of the Hands in Young People,' *St. Bartholomew's Hospital Reports*, vol. xxix., 1893.

† 'Uniradicular Palsies of the Brachial Plexus,' *Brain*, 1902, p. 299.

‡ 'The Seventh Cervical Rib and its Effect upon the Brachial Plexus,' *Medico-Chirurgical Transactions*, vol. lxxxviii., p. 109, 1905.

against the under side of a table, holding it there by the upward pressure of the left knee against the outer side of the right knee, which was crossed over the left one. In both there was pressure upon the peroneal nerve. Injuries to the nerves of the lower limb are likely to be slower in recovery than in the upper.

Cases are met with occasionally in which symptoms occur resembling those of a peripheral neuritis, but due to a central lesion in the spinal cord. The presence of increase in the knee-jerks, and the incomplete limitation of the symptoms to a single branch of the sciatic nerve, should be taken as signs that such a form of paralysis is central and not peripheral. The results of treatment in these cases are not good, whereas with strictly peripheral cases they are generally satisfactory.

248. **Pes Cavus.**—This condition may occur from atrophy of the interossei. But many cases of pes cavus on electrical testing show the reactions of the interossei to be normal, and the deformity in these cases seems due to spasm of the long flexors and long extensors rather than to weakness of the intrinsics of the foot. Cases of this kind are seen in young persons after puberty, with a history of gradual onset, and both sides are commonly involved. When the knee-jerks are increased and the leg muscles are large and firm, and the interossei give normal reactions, the cases are suggestive of primary spastic paraplegia. In these cases electrical applications do no good.

249. **Neuralgia — Referred Pains.** — The word neuralgia is applied to many different conditions in which pain is felt in the course or the area of distribution of a nerve, and the term might perhaps be defined as pain in the region of a nerve in which no inflammation or other morbid state can be discovered. The pain of neuralgia is also generally an intermittent pain. It is well known that a neuralgic pain in one part may be set up in a reflex way by irritation acting upon some more or less remote part. Fagge has given as an instance the trigeminal neuralgia so often excited by disease of a tooth, and severe supra-orbital pain may be instantly produced in some people by the eating of an ice. Neuralgia of the testis from renal calculus is another familiar form of reflex neuralgia.

Head has elucidated the whole subject of reflected or referred pain in a masterly series of papers,* and has conclusively shown that the whole surface of the body can be mapped out into

* *Brain*, Parts 61, 62, 67, 1893, 1894.

areas, each of which corresponds to certain visceral organs. In cases of referred pain we are enabled through Head's researches to form useful opinions as to the probable position of the irritation concerned in any given instance, and this greatly increases the chances of successful treatment.

An important point in true referred pains is the frequent presence of cutaneous tenderness. This has been pointed out by Head and Mackenzie, and is especially insisted on by them as a valuable means of distinguishing between referred and other forms of pain.

When we compare sensory with motor nerves we find an analogy between anæsthesia and paralysis, and between neuralgia and muscular spasm. The two latter are especially associated with irritation, direct or reflex, of sensory or motor nerves or nerve centres. And we may also learn from the comparison of motor and sensory phenomena that, just as in the case of paralysis the lesion producing it may be in the motor fibres or the ganglion cells, or in the motor tracts of the spinal cord or brain, so too in the case of sensory disturbances, the lesion producing them may occupy any part of the sensory tract, peripheral or central. For example, the neuralgic pains which follow herpes zoster are due to changes in the posterior root ganglion. It is therefore necessary before arriving at any final opinion as to the cause of a neuralgic pain, to explore all those parts so far as is possible.

It is useful to distinguish between pains referred to the area of distribution of a sensory nerve and pains felt along the course of the nerve trunk itself. The former are more particularly associated with the sensory fibres proper, and the latter with the *nervi nervorum* which supply the perineurium of the nerve trunks with sensibility.

In all cases of neuralgic pain it is of especial importance to examine carefully for the possible existence of pressure or deep-seated inflammation of nerve trunks as a cause of the pain. Thus a brachial neuralgia may be due to new growths of the cervical vertebræ, and sciatica to inflammatory processes or new growths in the pelvis.

The electrical treatment of painful affections takes either of two different directions. In the treatment of referred pains the principle of counter-irritation is followed, and by the production of painful cutaneous impressions it is sought to create a diver-

sion, as it were, in the nature of the impulses conducted along the nerve, and so by influencing the centres to remove the neuralgic condition. Counter-irritation is a very popular treatment for neuralgic pains, and electricity affords a counter-irritant of great convenience in application, because it does not damage the skin in the way that blisters or the cautery do.

The areas supplied by the fifth cranial nerve are often the seat of referred pains. These are excited by disturbances in many parts of the head, neck, and face. The nose, the eye, the ear, the teeth, the tongue, the salivary and other glands, the tonsils, the larynx, and lastly the brain itself, are enumerated by Head as sources of referred pains in the trigeminal or other areas of the head and neck. Neuralgias of the head and neck are also produced by irritations coming from many of the viscera. When it is remembered how large a part of the thoracic and abdominal viscera receive a nerve supply from the vagus or the glosso-pharyngeal nerves, which are of cranial origin, this connection between disturbances of the viscera and referred pains in one or other area of the head and neck becomes intelligible.

The form of trigeminal neuralgia which calls for special notice is that known as tic douloureux. The great suffering produced by this condition often leads patients to undergo severe surgical operations for its relief. This complaint is entirely different in its nature to the "referred pain" group of neuralgias. Frequently it is a central affection of the Gasserian ganglion, or of the central nucleus of the fifth nerve.

In the treatment of this form of trigeminal neuralgia no benefit can be obtained from the ordinary procedures of electrical treatment which suffice for the simpler reflex neuralgias of the face. In general the attempt to treat such cases in this way serves only to determine a paroxysm of pain. A method of treatment by electrical applications, devised by Bergonié, has proved successful in a certain number of cases in the hands of several different observers, and deserves attention in this country. It consists in the use of very large currents applied by means of an electrode which is so shaped as to cover the entire side of the face. The polarity preferred for the active electrode is the positive; the current should be pushed to a magnitude of 60 or 80 milliampères. If great care is taken to mould the electrode carefully to fit the surface, and if the currents are very gradually increased at the commencement, and

very gradually reduced at the end of the application, they can be borne without discomfort and without damage to the texture of the skin. The duration of each application should be half an hour, and it must be repeated daily until the tendency to paroxysms of pain has disappeared. The skin may still be tender to a touch, but, if no paroxysms are felt, a month's interval should be given, and then the applications are to be repeated as before at longer intervals.

The electrode applied to the face is made of metal cut out roughly in the shape of the capital letter E; the three branches are applied to the forehead, cheek, and chin, the eye and the mouth occupying the two gaps between the branches. The patient must recline on a couch during the application. The indifferent electrode is also to be a large one adapted to the upper part of the back, or to the abdominal surface. Bordier recommends aluminium as the most convenient metal for the electrodes.*

More recently the treatment of intractable trigeminal neuralgia by the introduction of ions of quinine or salicylic acid electrolytically has been advocated.

Leduc† has reported the cure of a case of this kind after it had for four years resisted other remedial measures. A single application of the ions of quinine produced permanent relief The following is an abstract of the case :

A female, aged sixty-eight years, previously healthy, developed, after exposure to cold, an acute attack of convulsive tic. The pain, which was constant, but subject to very frequent exacerbations, was limited to the area of distribution of the submaxillary branch of the left trigeminal nerve. The paroxysms were irregular, set up by a multitude of causes, mental and physical, and more especially by cold. For four years prior to undergoing electric treatment she was unable to handle anything cold—much less take a cool drink—without experiencing an immediate exacerbation. Hyperæsthesia of the skin was so marked that the slight variation in temperature caused by the opening of a window was sufficient to provoke a paroxysm. Her rest at night was greatly disturbed. She had tried all

* See *Archives d'Électricité Médicale*, 1897, p. 377, for a series of cases reported by Bergonié, Bordier, Guilloz, and Debedat; and *Ibid.*, 1902, p. 135, for a successful case reported by Vernay of Vienna.

† *Archives d'Électricité Médicale*, July 25, 1904.

kinds of medicaments in large doses without experiencing any relief. Every tooth, although sound, on the affected side was sacrificed, but without effect. On September 20, 1902, the nerve was divided, after which the attacks ceased for four days, only to recur with the same frequency and intensity. In March, 1903, a resection of the alveolar border of the lower jaw proved equally ineffective. On February 25, 1904, when she consulted Dr. Leduc, her condition was as bad as could be. The introduction of salicylic ions was first tried, and twelve applications were made, but owing to her great distress, the sessions had to be cut short and a current of too low a strength employed. This treatment afforded her some relief, and the frequency and intensity of the paroxysms were reduced, whilst the period of sleep was extended. The effluve of high frequency, which was subsequently tried, seemed to act like a current of cold air in provoking paroxysms. On June 3 bichloride of quinine in 1 per cent. solution was electrolytically applied, with a current gradually raised to 20 milliampères for thirty minutes, and gave rise to an œdematous redness of the skin, but resulted in a marked diminution of the pain and number of neuralgic attacks, as well as in an increase of sleep. The improvement was even more marked on the two following days. On June 5 she had two small reminders; these were the last. On June 6 the parts were much discoloured and desquamating; hyperæsthesia very much reduced. A second application was made by way of precaution, and since then she required no further treatment, being absolutely free from pain.

Roentgen rays have also been tried for neuralgia, and C. L. Leonard* has recorded some successful results.

250.—**Perineuritis.**—The distinction between pain in the area of distribution of a nerve and pain in the course of a nerve trunk has already been touched upon. In the latter case the disorder is most probably situated in the interstitial tissues or sheaths of the nerve trunk, and the pain is an expression of the implication of the *nervi nervorum* in the morbid process.

Most of the painful affections of nerves may be classified either as referred pains or as perineuritis. Cases belonging to the first group may be treated successfully by induction-coil applications, which relieve by their action as a counter-irritant, but the method is by no means suitable for painful neuritis or

* *American Medicine*, July 8, 1905

perineuritis, as we have already stated. The treatment of tender nerve-trunk cases is an important part of electro-therapeutic practice, but is by no means a simple matter, for in many instances the affections which come under this category are of an obstinate character. Sciatica and brachial neuritis are two familiar types of painful neuritis for which electrical treatment is frequently applied, and though they are common disorders, there is a certain degree of misapprehension as to the principles to be followed in applying treatment.

It is a commonly accepted notion that massage is good for these disorders. Gymnastic exercises, too, are often recommended as a means of obtaining relief, and patients will often persevere with these kinds of treatment in spite of an increase of pain as a result of doing so.

The cardinal principles upon which the treatment of painful neuritis should be founded are rest, warmth, and electricity, and the latter must be used as a sedative and for its vaso-motor effect, and not as a stimulant of muscular or nervous activity. The direct current must therefore be used exclusively, so long as there is any pain in the nerve trunks when the affected limb is at rest. When the later stages of the case are reached, and pain is felt only during certain movements, the activity of the congestion or inflammation is less severe, and the sinusoidal current, administered through the medium of the monopolar or dipolar bath, is a very useful mode of treatment.

251. **Brachial Neuritis.**—This is a common form of nerve-trunk pain, and one which may last a long time. The usual causes are injury or exposure to cold; while gout, alcohol, rheumatism, or syphilis may be predisposing causes.

It is important to exclude pressure from aneurysm or new growth, before making a diagnosis of simple neuritis. A common instance of brachial neuritis is the pain in the shoulder formerly called deltoid rheumatism, which is a neuritis of the circumflex nerve.

In other cases the neuritis may involve a greater or lesser part of the brachial plexus, and the pain may be severe. Thus, in one patient who was under my treatment, a touch in the axilla was sufficient to cause violent shooting pains, which were felt down the arm and forearm, and even in the hand.

The important points in the treatment of brachial neuritis are to prescribe rest, warm applications, and with electricity, the

direct current. Induction-coil applications, massage, and exercise are all bad, and tend to make the condition worse. This is especially the case when there is pain even during quiescence of the limb. Both in brachial neuritis and in sciatica this forms a useful means of estimating the severity of the case. When they are acute, the pain is felt even when the limb is at rest, and often it is severely felt during the night-time. If, on the other hand, the pain is only felt during movement, the case may be considered to be less serious, and more vigorous measures may be used in treating it. At that stage the sinusoidal arm-bath may be usefully employed to supplement or to replace the direct current.

Large electrodes and large currents are recommended, the positive pole over the cervical spine, the negative to be moved smoothly over the whole affected area.

252. **Sciatica.**—This term is applied generally to pain felt in the region of the sciatic nerve, and it covers several distinct conditions. Thus, the pain may be due to pressure upon the nerve within the pelvis, and it is well to remember that sciatica due to this cause is sometimes noticed in early pregnancy. New growth will also give rise to sciatic pain, and this must be borne in mind, particularly when the pain complained of shows a progressive increase in severity.

Sciatica may be a referred pain, and Head has pointed out that affections of the prostate may cause a referred pain whose distribution resembles that of true sciatica. The same may be said of piles or anal fissure. Pains due to morbid changes at the hip-joint may also be confounded with sciatica.

"Neuralgic" pains in the sciatic nerve may occur, but in most cases the affection giving rise to the pain of sciatica is a perineuritis of the trunk of the sciatic nerve.

The electrical treatment of a case of sciatica must necessarily be based upon a proper diagnosis of its cause. For the referred pains or neuralgias electrical counter-irritation with induction-coil currents is a successful treatment, and the effluve of a high frequency apparatus may also be used.

The treatment of sciatic neuritis or perineuritis must be conducted upon different lines. It will be necessary to follow the rules laid down in the preceding paragraph, and to use direct current for its sedative effect and its vasomotor effect. As large currents are needed by reason of the deep position of the nerve,

it is necessary to use large electrodes, and to give long applications. Fifteen or twenty minutes is a proper duration, and the current may reach 30, 40, or 50 milliampères.

One electrode should be held by the patient against the corresponding iliac fossa, while the other is applied along the course of the nerve on the posterior aspect of the thigh. Authorities differ as to the best direction of the current. Steavenson* recommended a descending direction, with the kathode applied in a labile manner along the back of the thigh, and the anode fixed on the lumbar spine or on the abdomen.

Direct applications of high frequency, by means of pads applied in the same manner, have also been of use in the treatment of sciatica of the neuritic type.

In clinical practice the treatment of sciatica is often very tedious. Patients will often drag on for months with an old-standing sciatica which no treatment appears to relieve. The reason for this is not difficult to understand. In the early stages of sciatica there is congestion or inflammation of the nerve trunk, and the pains are not usually so acute as to compel the patient to lie up. Consequently the limb does not receive the rest which is essential to recovery, the congestion is increased by the actions of standing, of walking, and of sitting, until eventually adhesions are formed between the nerve and the surrounding tissue, and these irritate the nerve during movement and keep up the pain.

A thickening of the sheath of the nerve may also be caused by the long-continued congestion, and this thickening tends to interfere with the nutrition of the nerve. Moreover, it commonly happens that massage is tried in an early stage of the attack, or the patient may try to "walk off" the complaint. The result is that cases of sciatica of long standing are abundant, and are very difficult to relieve by electrical treatment of any kind.

In the early stages of sciatica due to perineuritis the constant current must be used, and the urgent need of rest should be insisted on. This treatment should be uniformly followed so long as the pain in the trunk of the nerve is felt during conditions of repose.

When the acuteness of the attack is subsiding, and pain is only felt in movements of the limb, a very valuable treatment is

* *Lancet*, January, 1884, and July, 1886.

that of the electric dipolar bath with sinusoidal current. This gives rapid relief to very many cases, and a test which will determine whether sinusoidal baths are suitable for the case can readily be applied by giving a bath and observing the effect. If the patient finds that the application provokes the sciatic pain, the nerve is still too sensitive to bear this form of application, and the direct current must be continued for a longer period. On the other hand, if the patient feels comfortable in the bath, the case is ripe for treatment on those lines.

The condition of a patient whose sciatic pain is due to adhesions is often deplorable. The pain goes on for month after month, in spite of applications of various kinds, and the question of treatment is a very difficult one.

It is quite certain that adhesions may cause sciatic pain, and that the breaking down of an adhesion may be followed by the disappearance of the sciatica.

Thus, a patient of mine, who had had sciatica for nearly twelve months, experienced a sudden pain in the back of the thigh. It occurred as the result of a careless movement made while he was dressing himself. So severe was the pain, that he went back to bed, but in a few days the pain had subsided and his sciatica had disappeared.

An operation for the exploration of the nerve and the division of any adhesions found will often put an end to a sciatica due to this cause. The operation of nerve-stretching was no doubt a method of breaking down adhesions, but it was accompanied by considerable risk of injury to the nerve fibres, and is now less often practised. A better operative procedure is the division of any adhesions found, and perhaps the longitudinal splitting of the sheath of the nerve, if that is found to be thickened.

The possibility of breaking down adhesions by massage or manipulation of the limb should be borne in mind before deciding upon a surgical operation. As the employment of massage in early sciatica has already been condemned, it will be seen that procedures considered injurious in early cases of sciatica may be of prime value at a later stage of the complaint, and the difficulty will be to decide when any given case is to be treated according to the one method and when according to the other. In a general way it may be considered that pain occurring only on movement, and especially if it occurs only with special movements, is due to adhesions. The principles laid down

in the preceding sections will serve as a guide in the treatment of neuralgic and neuritic pains respectively.

253. **Acroparæsthesia.**—This name is given to a condition which is common in out-patient practice, and appears to h ave been first described as a clinical entity by J. A. Ormerod.* The patients are generally women between the ages of forty and fifty-five years, and they complain of feelings of numbness and tingling in the hands and forearms. The symptoms are especially noticed in the morning on awaking from sleep, and patients often say that they are in the habit of rubbing the hands when they wake in order to bring sensation back. A dull aching or burning feeling is also complained of, and some muscular weakness is present. Rarely there may be a little wasting of the intrinsic muscles of the hands. Treatment by arm-baths with sinusoidal or interrupted current gradually removes the trouble, though it may last for several months. Bromides are useful as a drug treatment.

* 'On a Peculiar Numbness and Paresis of the Hands, *St. Bartholomew's Hospital Reports*, vol. xix., p. 17, 1883.

CHAPTER XIII

THE NERVOUS SYSTEM—THE SPINAL CORD AND BRAIN

Infantile paralysis—Progressive muscular atrophy—Locomotor ataxy—Hemiplegia—Chorea—Writer's cramp—Exophthalmic goitre—Insomnia—Hysteria—Mental disorders.

254. **Electricity in Nervous Affections.**—Much time has been spent over attempts to arrest the degenerative spinal cord diseases by electrical applications, but hitherto without success. Still, it may be that some day a successful method of electrically influencing the nutrition of the spinal cord will be discovered. The effects of electrical applications upon the brain and cord have not yet been very fully worked out.

During the past fifteen years I have had opportunities at St. Bartholomew's Hospital for treating a considerable number of cases of locomotor ataxy, of progressive muscular atrophy of various types, of lateral and disseminated sclerosis, and of chronic myelitis, and have given them courses of electrical treatment with baths and sinusoidal current during weeks or months. I have never been able to satisfy myself of a complete cure in any unequivocal case, although I have thought that, in certain instances, the progress of a case was temporarily arrested by the applications. For instance, patients have often returned to ask for a further course of treatment, as they had lost ground after its discontinuance ; this is often the case with myopathic atrophies. A few cases of early or doubtful tabes have appeared to have been cured. One patient sent as a case of pseudo-hypertrophic paralysis, and with symptoms closely resembling that disease, did recover completely, but the diagnosis was a little doubtful from the first.

X-rays may prove useful in revealing disease of the vertebræ in obscure spinal affections, and E. v. Leyden has mentioned two cases in which a mistaken diagnosis of cord disease was set right by the discovery of caries of the vertebræ on X-ray examination.

255. **Myelitis.**—Electrical treatment is certainly useful when, as the result of an attack of acute myelitis, a patient is left with weakness of the bladder or of the lower limbs. I have seen the systematic application of direct currents longitudinally along the spine produce very definite improvement in such cases. Thus, in one case the patient, three years after the acute attack, could walk only with difficulty; his back muscles were so weak that he could not sit up for more than a few minutes at a time, and his sphincters were uncertain. He has so far improved under treatment as to be able to walk for several hours a day, to go shooting, and to play lawn tennis.

In his case the treatment has been by direct currents applied longitudinally along the spine. His manservant was taught how to carry out the applications, which were given regularly for ten minutes daily. The improvement was slow, but has been continuous from the time when the electrical treatment was begun. Sinusoidal treatment in baths also seems to be useful in some of these cases.

256. **Infantile Paralysis.**—There is no doubt that electrical treatment is of the utmost value for the development of muscles damaged by this disease. From the result of an electrical testing which has shown seriously impaired reactions, many children have been thought to be beyond the reach of treatment; but it is quite certain that prolonged electrical treatment will do good to nearly all cases of infantile paralysis, particularly if not more than a year or two has been allowed to go by since the incidence of the disease. Even after that lapse of time something may still be done.

There is a formula in which the prognosis of infantile paralysis has been commonly summed up. It is as follows: If the ganglion cells supplying the muscle are destroyed, recovery must be impossible, and if the cells are not destroyed, treatment is unnecessary, because the patients will get well of their own accord. This formula is widely accepted, but it has done much harm. It requires the assumption that the disease must either destroy all the motor cells of a muscle, or else must leave them all uninjured, and this assumption is certainly not correct. On the contrary, the damage to the motor nucleus may be of any degree of severity or of any extent, and the paralysis may vary between slight weakness and complete loss of all motor power.

It is reasonable to suppose that a focus of disease in the

anterior cornu of the cord may destroy some of the nerve cells of the nucleus of origin of a muscle, while others in the same nucleus may escape, and this might especially be the case if the nucleus of origin is an extensive one. On this point the statements of Sherrington are conclusive. In the *Medico-Chirurgical Transactions*, vol. lxxxii., p. 456, he writes: "The position of the nerve cells sending motor fibres to any one skeletal muscle is a scattered one, extending throughout the whole length of the spinal segments innervating that muscle; in the limb regions many muscles receive their motor fibres from as many as three consecutive spinal roots, and the bodies of the nerve cells innervating those must, therefore, inside the cord, extend through the length of three whole segments of the cord as a continuous columnar group, and in each transverse level of the cord these cells must lie commingled with nerve cells innervating many other muscles."

This being so, one can readily understand how a muscle may be crippled by poliomyelitis, and yet may survive in part through the support of such of its ganglion cells as happen to have escaped destruction.

Duchenne long ago pointed out that a muscle damaged by infantile paralysis may still contain a few living functional muscle fibres, and that these may easily be overlooked in an ordinary electrical examination of the muscle, but that they can be successfully cultivated by persevering treatment. There is no doubt that cases admitting of such an interpretation do occur.

If the surviving fibres can by cultivation be made numerous enough to have some useful voluntary power, they will be able to maintain themselves in a way which is impossible to them if they are unable to do any work. I had an opportunity of testing and dissecting the muscles in an amputated leg, the seat of severe infantile paralysis of old standing. The age of the patient was twenty years, and the limb had been paralyzed from childhood. The muscles of the leg were all extremely atrophied, degenerated, and fatty—in fact, the calf was almost like adipose tissue, but still contained a sufficient number of normal muscle fibres to show visible contractions to the induction-coil current. The other muscles of the leg, though in a state of advanced atrophy, all contained some fibres which were able to respond either to the induction coil or to the battery current. These reactions showed that even at that time there must have been

some surviving ganglion cells in the affected portion of the cord, and that a certain degree of trophic nervous influence was still available for the muscles of the paralyzed limb. Its hopeless condition at the time of the amputation was the result, not only of the old attack of poliomyelitis, but also of the sixteen years or so of disuse, and it is probable that sedulous treatment by electricity, gymnastics, and massage in childhood would have enabled the limb to recover sufficiently for it to have been of some use to its owner.

The persistence for several years of a reaction of degeneration in cases of old infantile paralysis is a peculiar phenomenon, and implies, I believe, that the muscles showing it are not without some representation in their spinal centre. In cases of complete division of a nerve trunk, the muscles cease to react at all to electricity in a year or less, but in infantile paralysis a well-marked reaction of degeneration may be demonstrated ten or twelve years or more after the original attack; and this is a clear distinction between the condition of a muscle cut off completely from its nucleus of origin by section of its nerve, and a muscle paralyzed and wasted by severe poliomyelitis.

Among muscles damaged by infantile paralysis three degrees of injury may be noted. In one the muscles are wasted, but they present reactions which, though weak, are normal in quality both to the induction coil and to the battery current. In the second group the muscles are paralyzed, atrophied, and show a reaction of degeneration, while the third group show no visible reactions at all.

It can be said of the first group that they tend to recover spontaneously, but if left to themselves recovery is slow and imperfect. Under treatment they usually advance more rapidly, even when the affected limb has been left very thin and weak.

It is well known that muscles paralyzed by poliomyelitis may recover spontaneously, but may remain in a state of imperfect recovery, even though their electrical reactions are normal, and these derive benefit from systematic electrical treatment. I have seen improvement start at once with treatment in a previously untreated case of fifteen years' standing.

With cases of the second class—namely, those with the reaction of degeneration—it is quite a mistake to say that they are incurable, and that electricity can do nothing for them. Electrical reactions of normal quality, and useful voluntary power

may return in muscles which for a long time have shown RD and loss of voluntary power, and this I have seen a number of times.

In a child with a history of paralysis which came on at the age of five months, treatment commenced in June, 1891; she was then three years of age. There were no reactions in any muscles of either leg, there was extreme wasting, and marked talipes equino-varus in the left foot. She was quite unable to stand. After three years' treatment her legs showed reactions to the induction coil in nearly all the muscles on both sides, and she could walk, though this was done in a rather awkward manner, because one quadriceps extensor muscle remained thin and weak. This case affords a clear instance of the good effect of electrical stimulation upon the nutrition of greatly enfeebled muscles, which at one time seemed to have fallen into the last degree of atrophy and paralysis.

I have notes of numerous cases in which normal reactions and voluntary power have returned in muscles long paralyzed with RD.

The following illustrates this class of case :

C. F., onset of paralysis in 1894. When seen in the same year there was RD in front muscles of right leg, with feeble normal reactions in the peronei, and no reaction of any kind in the calf muscles or in the tibialis posticus. Next year there was slight return of voluntary power. In 1899 voluntary power was much greater, and there were normal reactions of good quality in the peronei and the front muscles of the leg, with the return of a reaction (RD) in calf and tibialis posticus.

The routine treatment with infantile paralysis should be as follows: At the first examination the muscles are tested carefully, and the result is recorded, the girth of the affected limb is measured, the voluntary power of the paralyzed muscles is ascertained, and any faulty attitude of the limb noted. A note must also be made of the colour of the limb, its temperature, and whether chilblains or scars of chilblains are present or not. The mother or the nurse is instructed how to carry out a simple form of electrical treatment with a bath and an induction coil, and is further told to rub the affected limbs every night for a quarter of an hour. She must also be shown how to exercise the weak muscles by means of appropriate movements, and must take pains to make the child try to do its best to move the limb accordingly. If irons or other orthopædic appliances are

worn, the child is to be made to exercise its limbs without them for a certain time every day.

In addition to the treatment in the bath a direct treatment of the weakest muscles by means of electrodes may be advised when the management of the case is in intelligent hands. Either the coil or the battery current can be used for this, as may seem most advantageous, and it is best that this part be reserved for the medical man's own application, because applications of direct current require medical supervision. Periodical testings and examinations must also be made to see how the case progresses.

The first signs of improvement are a better circulation in the affected parts, disappearance of chilblains and sores, and a gradual gain of voluntary power.

The return of electrical reactions comes later, and it is usual, when all contractility has been lost, for a weak reaction to the induction coil to return first. This means that the few latent normal fibres in the wasted muscle have begun to grow and to gain sufficient strength to produce a visible contraction.

When the lower limbs are the seat of paralysis, as is usually the case, the electric bath is an excellent method of applying the electrical treatment. A rhythmic interrupter may be employed with great advantage, and the child, dressed in a short waistcoat, is put into the bath in a sitting position. The current is very well borne in this way, and the whole extent of the paralyzed parts comes simultaneously under treatment. The strength of the current is gauged by putting the hands into the tub, one at each end, and by watching the effect upon the child, the current being made weak at first, and strengthened gradually. It must not be so strong as to cause rigidity of the muscles. This plan requires no special knowledge of anatomy; it is efficient and likely to be persevered in, and this point of perseverance over long periods of time is the key to success. Even if only one of the lower limbs be affected, there is no reason why the bath should not be used, and if the sound leg be flexed and drawn up, most of the electrical current can be diverted into the affected one.

The following summary represents the writer's views upon infantile paralysis:

In every case of infantile paralysis which is not clearing up satisfactorily, it is important to apply electrical treatment, continuing it for six months or a year or more.

It is the exception for a muscle to be so completely destroyed by poliomyelitis as to be left without any functional fibres, and these remaining fibres can be cultivated by persevering stimulation of them.

Where the muscles show only the reaction of degeneration, or even when reactions are entirely abolished, some improvement may be hoped for in a good percentage of cases.

The amount of restoration which is possible in a muscle will 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 electrical reactions are not altered in quality, it is not good practice to leave the case to take care of itself.

257. **Progressive Muscular Atrophy.**—The electrical reactions differ in the different forms of progressive muscular atrophy. In the myelopathic forms the gradual degeneration of the muscle, fibre by fibre, produces a condition in which some fibres may still react normally, while others respond only by a reaction of degeneration. Thus, it is sometimes possible to recognise in an affected muscle a quick contraction followed by a sluggish one, the latter being produced by the degenerated fibres and the former by those which are still sound. As the degenerated fibres soon waste away, the final stage of an affected muscle is a stage of extreme atrophy, without any visible reactions at all.

In the type described by Dr. Tooth as the "peroneal" type, and also known as the "Charcot-Marie" type, it is possible to observe a reaction of degeneration in some of the affected muscles. In general, however, the muscles in cases of this type of atrophy show simple diminution to coil stimuli, and normal behaviour to cells. The diminution of response to coil currents ("faradism") may be extreme, and there is also diminution in the sensory perception of induction-coil currents. As atrophy advances, all reactions become increasingly difficult to provoke.

In the myopathic forms of atrophy the reaction of degeneration is not observed, and the only changes observed are quantitative, simple decrease or total loss of response to coil and to cells being the rule.

In none of the diseases included in the general title of progressive muscular atrophy can it be said that the prospects of

cure by electricity are good. Still, in default of any other better method of treatment, it is reasonable to believe that the use of electricity is a step in the right direction, and it is quite right that efforts should be made to obtain relief by means of electrical treatment. In the spinal forms Erb considers that he has seen relief, retardation, and even arrest of symptoms, especially in early cases, and advises treatment of the spinal cord. His method is to use the battery current, and to make the applications to the cervical spine, the cervical sympathetic, the lumbar enlargement, and the peripheral nerves, treating particularly the cervical enlargement, which is so frequently the seat of the most severe atrophic changes. Finally, the affected muscles are to be treated by the induction coil current, which should be moderately strong, though too vigorous a treatment is not advisable.

He adds that although electrical treatment may retard or arrest the progress of the disease, yet it is in no way a cure, and that the successful results said to have been obtained are generally the consequence of errors of diagnosis, especially in cases of neuritis, infantile paralysis, and atrophy after joint affections. He considers myopathic atrophies to have a more favourable prognosis, as he has seen great benefit follow electrical treatment in long-standing cases of that kind. Duchenne* states that by means of induction-coil treatment he had been able to arrest the progress of the disease in an advanced case (which seems to have been undoubtedly one of "myelopathic" progressive muscular atrophy) to re-establish the power of the diaphragm, which had become seriously involved, to restore the bulk and vigour of an important muscle (the biceps), and to dispel the fibrillar twitchings, and that the recovery was persistent for several years, in spite of the fact that the patient returned to hard manual labour—a condition of things extremely likely, in Duchenne's opinion, to bring on a relapse. He is certain that he has seen an increase in the bulk of a wasting muscle from coil applications, but only in cases where the muscle had not altogether lost its irritability to coil currents.

High-frequency treatment has been tried in progressive muscular atrophy, and Denoyés has reported a case as being of this kind, which was very notably improved by high-frequency treatment, so that the muscles increased in bulk, and normal reactions

* "Élect. Localisée" (third edition), p. 500, description and figure.

returned in the deltoid, biceps and the common extensor of the fingers of both sides, in all of which a reaction of degeneration had been observed at the time of commencing treatment. An examination of the details related by Denoyés suggests that the case should be regarded not as a true case of progressive muscular atrophy, but rather as an instance of an attack of poliomyelitis associated with a febrile illness which immediately preceded the appearance of the muscular atrophy, and by which the patient was laid up for two months. The whole time from the onset up to the commencement of the electrical treatment was only seven months, and the patient was seventy-two years of age. The reactions are also unlike those of the diseases grouped under the name of progressive muscular atrophy.

258. **Locomotor Ataxy.**—The value of electrical treatment in this disease is not yet settled. At the same time it is certainly premature to dismiss electricity as useless in all stages of this complaint, although it is no doubt correct to say that in advanced cases of the disease electricity will not restore the tissues which have perished. A difficulty in determining the value of electrical treatment meets one at the outset in the natural tendency of the disease to become arrested in certain cases, particularly in those which come under treatment early. Another difficulty is that peripheral neuritis may be mistaken for locomotor ataxy.

Several of my patients with very definite signs of tabes have seemed to derive some benefit to their symptoms from a course of general electrization by means of electric baths. In others the application of direct currents to the spine has seemed to be of service, and it is this mode of treatment which has generally been adopted. The electrodes are applied at the dorsal and lumbar regions. Many writers on electro-therapeutics have been able to bring forward instances of relief to symptoms from electrical applications in tabes. In the *Arch. d'Électricité Médicale* of 1893, the notes of thirty-seven cases are collected together from various sources by Dr. Laborde, and the whole subject of the electrical treatment of tabes is critically examined in a paper which forms a valuable contribution to the subject. His summary is that in his own experience the treatment of the spinal cord by direct currents does not cure tabes, but in certain cases it can relieve the pains, the ocular disorders, the weakness of the limbs, or even the bladder troubles. Induction-coil currents

seem to act unfavourably. A further study of the subject is desirable.

259. **Myasthenia Gravis.**—Cases of this disease may come under the notice of those interested in electrotherapeutic matters because of the peculiar reaction (the so-called myasthenic reaction) which is met with in the muscles of such patients. The peculiarity consists in a rapid decrease in the amount of response shown by a myasthenic muscle when it is tetanized continuously by the interrupted current. In other words, a myasthenic muscle shows the ordinary physiological effect of fatigue with excessive and abnormal rapidity, so far as the tetanizing effect of the interrupted current is concerned; but in spite of this, it seems to remain just as responsive to the application of a single closing shock from a direct current source after the tetanization as before.*

260. **Hemiplegia.**—In the less severe cases of hemiplegia good results are commonly obtained by electrical stimulation of the affected limbs, and this is a very valuable fact, because so little can be done in other ways to improve the condition of old hemiplegic patients. I have seen great benefit produced by the electrical treatment of such cases, and that not once or twice only, but frequently. In hospital practice the difficulty with old hemiplegic cases is rather to know when treatment may be discontinued, for as a rule the patients seem to wish to continue attendance indefinitely. Improvement up to a certain point is the rule. After that continued treatment does very little. Much cannot be expected when there is well-marked late rigidity. The series of cases recorded by Professor Erb seems to show that after an attack of hemiplegia the muscles may remain in a crippled condition from a sort of torpor of some part of the motor tracts, so that they remain for a time beyond the control of the will, although there may be no absolute interruption in the conducting paths. Thus, a patient may at once recover much of his lost power after a single vigorous electrization of his affected limbs. It is therefore very important that this treatment should always be tried in cases where a patient is recovering imperfectly from hemiplegia. Treatment should not be commenced until four or five weeks after the attack, in order to avoid all danger of setting up fresh changes in the brain, and

* "The Clinical History and Post-mortem Examination of Five Cases of Myasthenia Gravis," E. Farquhar Buzzard, *Brain*, 1905, p. 438.

it may be repeated three or four times a week. A certain number of patients will be distinctly improved thereby. Most of the improvement likely to be obtained in this way may be expected to show itself in the course of the first month. It is also advised by Erb and others that further treatment may be directed to the seat of the lesion in the brain, the continuous current being employed, the anode to the forehead and the sides of the head, and the kathode to the nape of the neck, the former electrode being slowly moved to and fro (labile) without interruptions; this direction of the current has been chosen on account of its following the course of the motor tract. A current of one to five milliampères is recommended, and the active electrode should be of medium size. This treatment is to be carried out daily for four weeks, the duration of each sitting being not more than five minutes. If aphasia is associated with the hemiplegia, the anode may be applied to the region of the third left frontal convolution and island of Reil. I have no personal experience of the results of direct treatment of the brain in hemiplegia. As the morbid process in the brain is essentially a destructive one, there must be limits to the amount of recovery which is possible. These limits will be determined by the extent and the situation of the damaged part.

261. **Epilepsy.**—This has been attacked by electrical methods, but without any great advantage. Arthuis stated that he had seen good results follow from electrostatic treatment.

Althaus gives three cases where treatment at once diminished the frequency of the attacks, and went so far towards effecting a cure that the intervals between the fits were prolonged from a few days to two months. Erb also reports that he has received a decidedly favourable impression from the treatment of epilepsy by the constant current. He advises that the anode be placed first on the side of the forehead, with the kathode to the nape of the neck, with a weak current for one minute; and, secondly, in the middle line of the head in front with the same current, and for the same length of time, the kathode being over the occiput. The treatment of the seat of the aura as well is recommended by Althaus.

Branth has suggested the use of X-rays in epilepsy, and has reported a case of mixed *grand* and *petit mal* originating in childhood, in a man aged thirty-one, in which very decided benefit seems to have followed a course of X-ray treatment.

262. **Chorea.** — Statical electricity has been successfully used in the treatment of this disease. In 1849 Dr. Golding Bird* strongly advocated its use, and reported thirty-seven cases. Of these thirty had been cured by the treatment, while five of the others were relieved. The treatment adopted was the application of sparks to the spine. The patients were insulated and connected with one of the conductors of the electrical machine. A ball-electrode with insulated handle was attached to the other conductor, and sparks were applied to the spinal column and the affected limb, until a papular eruption was produced. In the case of children the mother or nurse was insulated with the child in her arms, and sparks were applied to the child's back and limbs as before.

The shocks from a Leyden jar were found to be harmful.

In *Guy's Hospital Reports* in 1853 Sir William Gull reported twenty-five cases of chorea treated by statical electricity. Nineteen were cured and five improved; only one resisted the treatment. He says: "The fact stands well established that electricity is at present to be ranked amongst the means at our disposal for the cure of chorea, and that in severe cases its effects are often truly surprising. Where other means cannot be employed; when the patient is scarcely able to swallow; where the skin is abraded from the prominent bones of the emaciated frame; when the powers of life seem nearly exhausted, sparks of electricity drawn from the whole length of the spine will often, after a few repetitions, effect a favourable change, and enable us to administer other means of cure." In spite of this emphatic testimony, the treatment is nowadays neglected.

In the few cases which have come under my own notice I have found such statical treatment very useful.

With modern machines the negative breeze to the spine will alarm the patient less and will prove equally efficacious.

It often happens that patients seem to recover imperfectly from chorea, because certain habitual movements remain when the disease has otherwise disappeared. For these late symptoms electrical applications are very suitable. I have seen them quickly dispelled in several such cases by a course of electrostatic treatment with sparks. Indeed, all those which I have been asked to treat for this condition have recovered within two or three weeks.

* "Lectures on Electricity and Galvanism," London, 1849.

The paretic states which are often left after chorea may be treated by electricity with great advantage.

General electrization in the electric bath is also useful. It is probable that the high-frequency effluve to the spine would act equally well.

263. **Spasm and Tremor.**—The numerous forms of tonic and clonic spasm and of tremor often come under electrical treatment by reason of their incurable character. When the symptoms are due to a degenerative process in the nerve centres, as, for instance, in paralysis agitans, in disseminated sclerosis, and in hemiplegia, electricity is not likely to be of service. Other forms of spasm and tremor, which may be of central origin, are relieved by electrical applications to the head and neck. The treatment is usually very slow to yield a favourable result. Erb has recorded a number of cases from his own observation and that of others.

Hysterical cases sometimes improve quickly under electrical treatment. Statical applications are perhaps the most suitable form of treatment for these cases.

It must not be forgotten that spasmodic affections are not infrequently reflex phenomena. Thus, there may be severe spasm of the muscles of mastication from inflammation about the gums or throat, and inflamed cervical glands sometimes cause wry-neck. Or there may be spasm from direct irritation of the nerves, as in wry-neck from disease of the cervical vertebræ. Before commencing electrical treatment a careful examination should be made for any source of irritation, and this, if possible, must be remedied.

In children and also, though less commonly, in adults wry-neck may be due to exposure to cold or wet, and this form has been called " rheumatic," and yields easily to simple measures.

264. **Writer's Cramp.**—This is the best-known form of a series of spasmodic affections which are produced by prolonged overwork of certain muscles, particularly when the work done is of a complicated and highly co-ordinated kind. The name of function spasm or occupation spasm has been given to this group. Besides those whose occupation is writing, violinists, piano-players, tailors, and shoemakers are subject to similar attacks in the muscles which they use most often. The symptoms of writer's cramp are also seen sometimes in persons who do not write much. In writer's cramp there is spasm associated with

muscular weakness, pain, and tremor, either of which may predominate. The chief seat of the cramp or palsy is in the intrinsic muscles of the thumb and first finger. If the occupation be persevered with, other muscles are called in to take the place of those which are deranged, and soon they also suffer.

The characteristic feature of these affections is that the weakness, or pain, or spasm, is produced only by one particular kind of work. The hand of a man with writer's cramp remains useful for everything except writing, and so with the other forms of true occupation spasm.

The results of electrical treatment are unsatisfactory.

Max Weiss,* in discussing the electrical treatment of writer's cramp, recommends the use of constant currents of from two to five or eight milliampères, for fifteen to twenty-five minutes, with absolute rest from writing ; applications twice daily during the first weeks, diminishing later to two or three times a week. Anode in the palm if extension is the main symptom, on the dorsum if flexion. Kathode to be placed on the nape of the neck or on the upper and inner part of the arm. The anode may also be applied to the tender points for ten to twenty minutes. Treatment to the motor cortex and to the spine at the lower cervical level should also be used.

265. **Tetany.**—This form of spasm, although not very common, deserves mention here, because of the peculiar increase in electrical irritability which forms one of its leading symptoms. There is also, as is well known, an increased irritability of the nerves and muscles to mechanical stimulation, and this is not confined to any particular nerve, although it has been most commonly observed in the facial nerve (facial irritability). The peculiar spasms can be evoked by compression of a nerve trunk or of the main artery of a limb, or by a rough touch over a motor nerve. Erb first showed that the electrical irritability was also increased in this disease.

In a recent paper Dr. Bernhardt has reported three cases in which the electrical reactions were examined. His results compared with the normal irritability of the same nerves are represented in the following table, which gives the current in milliampères required to produce the first KCC contractions.

* *Centralblatt für die gesamm. Therap.*, April, 1891.

Nerve.	Normal.	Tetany (3 Cases).
Facial - - -	0·9—3·0 milliampères	0·5 —1·5 milliampères
Median - - -	0·9—3·3 ,,	0·25—1·5 ,,
Musculo-spiral -	2·0—5·0 ,,	0·25—1·0 ,,
Peroneal - -	1·0—2·0 ,,	0·5 —1·1 ,,

ACC and KDT (kathodal duration tetanus) were also more easily produced than usual. In the electrical treatment of tetany the influence of the anode stabile is to be directed to the affected parts, and the current must be gradually diminished at the termination of the sitting to avoid the ill effect of sudden anodal opening. The results of treatment are said to be entirely favourable, but the disease is one which tends to disappear spontaneously.

266. **Exophthalmic Goitre.**—Quite a large literature has grown up on the electrical treatment of this disease. Many favourable cases have been reported with various kinds of electrical treatment. So long as the pathology of the disease remains uncertain, the electrical treatment must continue to be tentative. It is by no means successful in all cases, although numerous cures have been reported in the journals.

In this country Cardew reported* some cases in which the constant current produced great improvement in the symptoms. In nearly all of them the frequency of the pulse-rate was reduced, the enlargement of the thyroid was diminished, and the nervous condition of the patient was improved. He suggested that the treatment should be carried out by the patients themselves three times a day, and also at other times if the palpitation of the heart should become severe. He advised that a current of two to three milliampères should be applied for six minutes ; the anode to the region of the lower cervical spine, the kathode to the side of the neck (labile), from the mastoid process to the clavicle. The two sides of the neck should be treated alternately, and the patient should persevere with the treatment for two months at least. He also declared that the diminished resistance of the body which has been observed in this disease is due simply to the increased perspiration and moisture of the skin, and this opinion is now generally accepted.

* *Lancet*, July, 1891.

Owing to this lowering of resistance, a small electromotive force is sufficient to give the required strength of current. The number of cells in circuit must therefore be small, commencing with as few as three or four, and the galvanometer readings must be carefully attended to.

Induction-coil currents briskly applied to the neck have also been found efficacious.

Electrolysis of the enlarged thyroid gland has been warmly recommended by Dr. G. Vaudey, of Marseilles,* as a successful method of treating this disease. His views are based upon the need of reducing the activity of the gland, and he claims that this can be satisfactorily effected by electrolysis, and that the degree of reduction of the gland can be finely adjusted to suit individual cases. He considers that the needles used for the electrolysis must be insulated where they pierce the skin, and he advises the insulation to be applied by the surgeon a short time before the operation, by dipping them into a solution of shellac in alcohol of 80 per cent. strength. The proportion of shellac to alcohol is as one part to five. Steel needles are used, and they are connected to the positive pole ; the end is left bare for the distance of one-fifth of an inch, in order that the electrolytic action may be localized in the actual thickness of the thyroid gland itself, and there is no electrolysis in the skin and superficial tissues. The use of varnish protects the skin from the risk of disfigurement by black marks due to oxide of iron deposited from the iron of the needle. Dr. Vaudey states that an anæsthetic is not necessary, and he reports several cases in which excellent results, both upon the general state of the patient and upon the enlarged gland itself, followed his treatment.

Beck, after excision of one lobe of the enlarged thyroid, exposed the other lobe to X-rays. In two cases in which this treatment was carried out, in one eighteen and in the other three months after the operation, which had only produced an improvement, a remarkable diminution in the nervousness and tachycardia was observed. In a third severe case, in which the X-ray treatment was started a week after the operation by a daily exposure of at first five and then ten minutes, the improvement was immediate and rapid. At the end of a week the treatment was suspended for a week, when it was found that

* *Annales d'Électrobiologie*, 1899, p. 182.

the pulse had fallen from 160 or 180 before the operation to 80, and the exophthalmos had nearly disappeared. After that the X-ray treatment was given for five minutes each week. When seen five months after the operation, the remaining half of the goitre had disappeared, as had also the exophthalmos and tachycardia. It is, however, difficult to determine whether this satisfactory result is to be attributed to the operation or to the X-rays, or to both. R. Stegmann, in dealing with three cases of Graves' disease treated by X-rays with marked success, states that the idea that the breaking down of the gland substance and its absorption might produce hyperthyreoidism proved groundless. Upon the results of his treatment in these three successful cases he concludes that it is beyond question that a very favourable influence and cure of Basedow's disease is possible through radiation of the thyroid gland. Through the radiation of the pathological organ, a lesion of the glandular epithelium takes place, which produces a quantitative or qualitative alteration of its internal secretion. Widerman* has also treated five cases of typical Basedow's disease by radiation applied to the enlarged thyroid, with the results that the nervous symptoms were materially ameliorated in two cases, the general health was improved in all, and the bodily weight was notably increased. But no improvement was noticed by him either in the exophthalmos or in the tachycardia.

267. **Insomnia.**—General electrization frequently produces a tendency to sleep afterwards. The electric bath has an especially strong effect in predisposing to sleep; so has the static charge (positive) with head breeze. Armstrong has found central galvanization very useful (§ 186). Bonnefoy has pointed out that statical applications are specially indicated in subjects with a low arterial pressure, and are unlikely to be of service in the opposite condition of raised arterial tension.

High-frequency applications, which have a tendency to reduce blood-pressure, should be chosen in preference for patients of this latter class; and W. F. Somerville has stated that they often prove efficacious. He uses the method of the condenser couch, with currents ranging between 200 and 700 milliampères in the case of women, and slightly larger currents for male patients.

268. **Migraine and Headache.**—In typical migraine the results of electrical treatment are disappointing. In mild forms the

* *La Tribune Médicale*, January 27, 1906.

headache may be relieved by applications of the constant current longitudinally to the head. The static brush discharge to the scalp is also of service in some cases.

Central galvanization, electrostatic charging, the electric bath, or high-frequency treatment applied systematically between the attacks will often succeed in reducing the tendency to migraine. Many writers have preferred some form of general electrization for migraine, on the ground that it is a manifestation of impaired nutrition requiring general rather than local treatment.

The simple headaches of debility or fatigue are often dispelled at once by static charging. Constipation headaches are unaffected or made worse by this treatment.

269. **Hysteria.**—Hysterical affections have been very largely treated by electricity, and, from the peculiar nature of the affection, good results have followed the most diverse forms of electrical treatment. The moral effect of the treatment, particularly when it is associated with sparks or with shocks, is suitable to the state of mind of hysteria, and therefore the literature of Medical Electricity, from the time of John Wesley's "Desideratum" onwards, is full of more or less wonderful cures of such cases by electricity, acting no doubt in a psychical way. At the same time the action of electrical treatment lies rather in the direction of dispelling symptoms than of curing the morbid state, and it is necessary to be prepared for occasional difficulties and disappointments even in hysterical cases, although good results will often be obtained. We must also be careful not to claim too much for the electrical part of the treatment when it is successful, for it may happen that the touch of an electrode will cure even when there is no current. Several cases of this kind have come to my notice. Strong shocks have often been used for cutting short a hysterical fit, but the most useful rôle of electricity in hysteria is for the removal of paralysis, anæsthesia, or spasm; for these symptoms the induction coil is most usually employed, either with an ordinary electrode or with the dry metallic brush. Statical treatment, especially the treatment by sparks, is also valuable in these cases, and has been very largely practised.

Hysterical aphonia can sometimes be dispelled by coil currents applied to the thorax from outside, and for the most part this method is as good as the direct application of the electrode to the fauces or to the larynx.

The electrical treatment of hysterical symptoms does not depend merely on the severity of the applications. The treatment may be briskly applied, but pain must not be deliberately inflicted. In the treatment of functional aphonia by sparks or shocks there are cases where the patient becomes alarmed and screams out aloud, and so becomes cured. Others suffer in silence and do not cry out, and these are not so easily cured.

For the hysterical condition, as distinguished from the special symptoms, it is advisable to use general electrization, and especially the electric bath or treatment by statical charging and breeze.

Hysterical patients are considered to be bad subjects for high-frequency treatment.

An important consideration is the diagnosis between hysteria and organic disease of some obscure kind. It is not at all uncommon for hysteria to be associated with serious disease—for instance, with phthisis. Moreover, when the diagnosis of hysteria has been based upon the complaint of a persistent localized pain in a female patient, it may, after all, turn out that the pain is due to some serious latent mischief. I have known two cases where female patients with early malignant disease of the vertebræ complained of persistent pain, and were supposed to be suffering from hysteria alone.

270. **Mental Diseases.**—The abundant evidence which we possess of the value of general electrization in the simpler forms of nutritional failure seems to point to the importance of applying the same kind of treatment in certain forms of insanity or mental failure, especially if the general state of nutrition is not maintained. As a rule, cases of this kind are not often met with in general practice nor among the out-patients of general hospitals, and it will rather be in asylum practice that opportunities for trying electrical treatment will arise. A considerable amount of evidence has already accumulated to show that something may be done in this way. A valuable summary of the position up to about 1885 will be found in Erb's work on Electrotherapeutics, together with numerous references to the writings which should be consulted in connection with the subject. Three cases which have come under my own experience may be mentioned here. One was that of a man referred to me by Dr. Gee, with a note saying that the patient showed many of the signs of progressive dementia, but that, as his symptoms

dated from a recent attack of influenza, he might receive benefit from electricity. The patient recovered rapidly from a short course of sinusoidal bath treatment. He recovered his memory, which he had completely lost, and was able to go back to his work. Another patient was a shorthand writer who had broken down in health completely. He was strange in his manner, and sat huddled up in a dejected attitude. His wife said he was much changed in temper, and told me that on one occasion he had been found wandering about, and had been brought home by a policeman. When he came he was put on sinusoidal baths twice a week. A gradual improvement began, and all his symptoms slowly left him. After three months he was able to begin work again, and has continued well for more than four years.

A third case is very much like the last. A man of forty began to grow more and more helpless. He became unable to find his way in the street ; he stumbled easily, and several times fell down without adequate cause. His speech became slow, and he could attend to no business, and it was uncertain whether he understood what he read in the newspaper. Under electric bath treatment there was a slow improvement, perceptible first to his wife. In about two months' time he was able to come to the hospital alone instead of being brought there by a friend. Treatment was continued for nearly a twelvemonth, and during the last part of the time he was able to attend to the book-keeping of his wife's business. He spoke quickly and to the point, and no longer stumbled or fell down, and he described himself as " practically well." There was a gain in weight both in his case and in the preceding one.

The following communication from Dr. Robert Jones is noteworthy, as showing a simultaneous mental improvement and augmentation of body-weight in a series of cases treated under his supervision at Claybury Asylum by general electrical stimulation by the bath method, using induction-coil currents :

" I have tried the electric baths in the case of adolescents mostly. In these and others the form of insanity was that of melancholia, some of the cases presenting well-marked melancholia attonita.

" These cases are marked by a gradual deterioration as a rule. They stand or sit about in a fixed or passive attitude, and have almost always to be considerably coaxed (if not forcibly fed) in

order to get them to take nourishment. The mental condition is so unsatisfactory that some persons call the disease primary dementia, and it is certainly not a very curable form.

"After my conversation with you and my encouragement by your method of bath treatment, I tried it upon eighteen males and five females. The record of weight in the case of the females was not kept; of the five cases all improved greatly in health; two were phthisical, but whilst undergoing bath treatment both gained several stones in weight. One died of phthisis; of the others, one was discharged recovered, one has developed epilepsy, and one has recovered sufficiently to lead a useful life as a helper in the asylum.

"Of the eighteen men, nine have left the asylum (six recovered, two relieved, and one improved but not recovered). All the men gained weight under treatment (they were weighed weekly, and the record has been kept), the average gain of the nine who left the asylum being seven pounds during the bath treatment, which lasts for an average period of about seven weeks, but many received baths during nine or eleven weeks. The greatest gain of one case whilst under treatment was twenty-two pounds, the next nineteen pounds. Of the nine cases remaining under treatment, one is phthisical, one is suffering from progressive muscular atrophy; the others are considerably improved mentally, the stupor or profound melancholia having quite passed off, but they have not been well enough to be discharged from the asylum. I consider the results to be satisfactory. So little has yet been done in regard to the systematic treatment of the different forms of insanity by electricity that it is perhaps premature to form definite conclusions, but I consider that in electric baths we have an excellent and valuable stimulant to metabolism.

"I should especially recommend electric baths in melancholia in adolescents and apathetic cases such as I have referred to. Certain puerperal cases of melancholia have also done well under treatment."

CHAPTER XIV

THE CIRCULATORY SYSTEM—THE RESPIRATORY AND DIGESTIVE TRACTS—THE URINARY AND REPRODUCTIVE ORGANS

Passive congestion — Arterio-sclerosis — Laryngeal affections — Pulmonary tuberculosis—Gastric dilatation—Hæmorrhoids—Urethral stricture—Enlarged prostate—Nocturnal incontinence—Menstrual troubles.

271. **Disorders of Circulation.**—General electrization has been recommended in the treatment of some forms of cardiac neuralgia, in dilatation of the heart, and in cardiac dropsy. It is considered unsuitable for cases with marked arterio-sclerotic changes. Larat has advised the use of the sinusoidal current bath, and Cluzet mentions that improved compensatory changes, decrease of cardiac pain, reduction of anasarca, and better diuresis have been noticed in cardiac cases treated in this way. Caution should be observed at the commencement of a course of baths, as heart patients may show some dyspnœa or embarrassment of the heart as the result of immersion in the warm water. The temperature of the water should not be more than 93° F. at first, and the patient should enter and leave the bath gradually and cautiously.

The effects of electrization upon the blood-pressure have already been referred to in § 190. The static charge has a decided influence in raising the blood-pressure, and its effect is increased by the brush discharge or sparks applied to the region of the spine. The effluve and spark discharge of high frequency applied in the same way to the spine is said to produce a rise of blood-pressure, whereas treatment by "autoconduction" (§ 141) or the condenser couch lowers the blood-pressure.

Bonnefoy* has pointed out the important bearing of the blood-pressure characteristics as a guide in electrical treatment. After mentioning the good effect which statical treatment has

* "De l'Insomnie," *Cannes Médicale*, 1903.

upon neurasthenic symptoms, and especially upon the insomnia of neurasthenics, he relates two cases in which static treatment aggravated the insomnia. He found that in both instances the patients had high blood-pressures, and he considered that the increase of their already high pressure by the static electricity had the direct effect of making their symptoms worse. By changing the treatment from static to high frequency, he obtained a lowering of blood-pressure and a relief of the symptoms.

272. **The Relief of Congestion.**—The uses of electrical treatment for the relief of congestion and to promote the absorption of inflammatory products should occupy an important place in therapeutics.

This effect of electrical applications was investigated by Remak* in 1856.

He made use of the continuous current exclusively, and, so far as one can judge, the magnitudes of current employed by him were fairly large. There is no doubt that his views on the subject were correct, and that the direct current may be regarded as having a special power of improving the circulation in a part, and as being of great value in promoting the removal of œdema and of other chronic conditions due to inflammation. As an example of the effect of the battery current in relieving severe congestion caused by injury to a joint, the following case, reported by Remak, seems to be worthy of being reproduced in abstract :

" A washer-woman, aged thirty-six, fell from a table and felt her right foot to be twisted outwards ; so much pain was produced that she could not walk. During the rest of the day and through the night she applied cold-water dressings. The following day she consulted Remak ; she was obliged to drive to his house, and ascended the stairs with great pain and difficulty. He found the dorsum of the foot much swelled, livid, and very tender ; the diagnosis made was laceration of some of the tarsal ligaments and extravasation of blood. The aspect of the foot was such as to lead to the apprehension that gangrene might result. At the patient's urgent request, electrical treatment was applied. Owing to the thickness of the skin of the sole of her foot, it was necessary to use a large number of cells in order to produce any sensation or reddening of the skin. By repeatedly changing the place of application of the electrodes, he continued

* *Galvanotherapie*, R. Remak, 1856.

the application for twenty-five minutes. During this time the livid coloration disappeared, the œdema and the pain diminished considerably, and the patient could rest her heel upon the ground better than before. The warmth of the foot, increased by the current, continued until the evening, by which time a decided improvement was established, and she passed a good night without pain. Next day the colour of the foot was normal, and the symptoms were less severe ; the treatment was repeated on this and on the next three days. She was then so much better as to walk without lameness, and in a fortnight was practically well." The mode of application is not clearly stated, but it appears probable that the positive pole was applied chiefly to the sole of the foot, but also to the dorsum, while the negative was on some indifferent part higher up the limb or on the trunk.

The view taken by Remak is that the current produces a marked increase in the rate of circulation through the part treated by a general dilatation of its bloodvessels, and as a consequence of the improvement in the circulation the products of effusion are much more rapidly carried off than would otherwise be the case. A. Tripier * has recently written a suggestive paper on this subject, taking as his point of departure the observation that the application of interrupted currents to the scrotum causes active pulsation in the vessels of the spermatic cord. He further shows that in general the application of interrupted currents provokes a transient hyperæmia in the part treated, and shows how this reaction can be turned to useful account in many conditions of defective circulation — for instance, in local congestions of many kinds. The good effects observed in rheumatic conditions may be the result of these vasomotor effects.

Several writers have reported favourably of the treatment of ascites and of hydrocele by electricity. In ascites the induction-coil current applied energetically for fifteen or twenty minutes so as to set up vigorous and repeated contractions of the muscular walls of the abdomen, has been followed by increased flow of urine and disappearance of the ascites. The prospects of permanent cure must depend upon the cause of the ascites in each particular case.

273. **Raynaud's Disease — Chilblains.**—The electric bath is useful in cases of defective circulation, as in Raynaud's disease,

* "Contributions à l'Histoire Thérapeutique des Stases et Congestion Apyrétiques," *Annales d'Électrobiologie*, 1905, p. 624.

chilblains, cold feet, and in cases of ischæmia of the extremities. One of the first signs of improvement in cases of infantile paralysis is that the circulation is improved, the limb becomes warmer, and the chilblains disappear. The applications can be very conveniently made by the bath method. Either a general bath or an arm-bath or a foot-bath can be used.

In the disease which bears his name Raynaud has recommended the constant current, and Sir Thomas Barlow* has suggested its use in a monopolar arm-bath in the following words: "Immerse the extremity of the limb which is the subject of local asphyxia in a large basin containing salt and water; place one pole of a constant-current battery on the upper part of the limb and the other in the basin, thus converting the salt and water into an electrode. Employ as many elements as the patient can comfortably bear, and make and break at frequent intervals, so as to get repeated moderate contractions of the limb. In a typical paroxysmal case, if the two limbs are similarly affected, it will be found that the limb which is subjected to the above treatment will more rapidly recover than the one which is simply kept warm."

For chilblains the arm-bath or foot-bath with induction coil is the most convenient domestic remedy, and succeeds in all but the most severe cases. I have used this mode of treatment in a number of cases, and have repeatedly seen the prompt disappearance of chilblains follow its use. Moreover, patients have several times informed me that after the cure of their chilblains by a course of coil baths they have found themselves with more resisting power afterwards, so that a course of baths at the beginning of winter has been sufficient to get them through the whole of the cold weather without any return of the chilblains afterwards. The effect of the treatment, therefore, is more or less lasting. In the more severe cases of chilblains the constant-current bath must be used. Its effects upon the circulation seem to be more intense than those of the coil, and after a constant-current bath warmth and redness of the skin is greater than it is after a coil bath.

Patients who know by experience that they are likely to have severe "broken" chilblains should not delay too long before beginning with the treatment, as the current acts very painfully upon any raw ulcerated surfaces. If these already

* New Sydenham Society, "Selected Monographs."

exist, they must be covered with a strip of oiled lint during the bath.

274. **Arterio-sclerosis.** — The very important matter of the reduction of the blood-pressure in individuals in whom it has been raised by disease has been long and carefully studied by A. Moutier, whose numerous papers convey the impression that real and valuable progress in this direction has been achieved. In a paper written in 1904* Moutier reviews his former publications on the subject, and repeats the opinion that electricity, in the form of autoconduction by high-frequency currents, provides a means of reducing arterial pressure and of securing a return to the normal in cases of permanent hypertension. He states that in 1899 his researches had not yielded satisfactory results by the employment of d'Arsonvalization alone, but in arterial hypertension of long standing a combination of hygiene and dietetics with d'Arsonvalization would cause the disappearance of the most persistent arterial hypertension, and that, though slow, the reduction of the arterial pressure was progressive.

In 1902 he was able to speak more positively, and to affirm that cures might result when the disease was kept under treatment for a sufficient length of time, and if the state of the patient justified a favourable prognosis, considerable amelioration was always obtained.

In a certain number of cases he had observed that a reduction in the arterial pressure of 1 to 2 centimetres of mercury was secured after a single sitting. The pressure would rise a little later, and generally returned to its original normal state little by little. At each new sitting the reduction in pressure was definite and sure.

To obtain good results it is necessary to have powerful apparatus. The cage for autoconduction should be well made, without any break in the coil of wire. The coil should be a large one, and an oil-immersed condenser is to be preferred to Leyden jars.

In general, the normal degree of blood-pressure is obtained after six, eight, or ten sittings. If more are required, it is almost always due to one of the following reasons—viz., the existence of organic lesions, errors of diet, or constipation;

* "Traitement de l'Arterio-sclerose par la d'Arsonvalization," *Archives d'Électricité Médicale*, 1904, p. 701.

but he had never failed to obtain normal readings after sixteen or twenty sittings. The reduction in pressure, when obtained, tends to be permanent, and in individuals kept under observation for three years Moutier has observed no signs of relapse.

275. **Aneurysm.**—Electrolysis has been tried for the cure of aneurysms, particularly for those which are not suitable for treatment by ligature or compression. In many of the cases recorded some temporary increase of hardness has followed the operation, but the cures are but few, and the punctures made in the sac walls have sometimes led to hæmorrhage. The piercing of the wall of the aneurysm by the needles, with the consequent risk of bleeding, is the chief defect of the operation. It may be lessened by the use of needles insulated except near their point, so as to limit the electrolytic process to the interior of the aneurysm, and to prevent any action upon its wall.

The method which is generally preferred is to introduce both positive and negative needles into the tumour. The needles attached to the positive pole become corroded if they are made of steel, but this is not an objection, for coagulation is promoted by the salts of iron so produced. Ciniselli* has collected twenty-three cases; of these six recovered, sixteen died, and one case disappeared from observation. Some of those reported as cured had relapses a few months later. See also *British Medical Journal*, 1890, vol. i., p. 1276, for a report of successful results after thirteen sittings in a case of aortic aneurysm.

As far as can be made out from the details furnished, the electrolysis of aneurysm requires large currents and long sittings. Twenty, thirty, or forty cells have been used, and the application continued for half an hour or more. Assuming the internal resistance to have been 100 ohms (it may have been much lower), and putting the electromotive force of the cells used at one volt apiece, then twenty cells would give a current of about 200 milliampères, and forty would give twice as much. This current, if continued for half an hour, would be sufficient to set free a considerable amount of electrolytic gases, and in some of the cases we read that the tumours became resonant to percussion after the operation. The free acids and alkalies produced by the electrolytic separation of the neutral salts of the blood would probably soon recombine in their passage along the blood-stream. The clotting set up in the aneurysm is soft and diffluent.

* "Treatment of Thoracic Aneurysms by Electro-puncture," Milan, 1870.

Willard* has reported a case in which 20 feet of silver wire were inserted into an aneurysm and a current of 80 milliampères passed through it. The results were favourable, and the patient was able to leave hospital nine weeks later.

The diagnosis of aneurysm by X-ray examination is now comparatively easy, and it may be worth while to warn beginners against confounding the normal convex shadow given by the posterior portion of the normal aorta with the shadow given by aneurysms. This mistake has often been made because at a certain angle of incidence the shadow presents an appearance very like that of a small circular bulge at the level of the aortic arch.

276. **Cardiac Failure.**—The aid of electricity is often invoked for the purpose of resuscitation when death appears to be imminent. It may be applied either in the form of brisk general cutaneous stimulation, as in cases of narcotic-poisoning, or with the special objects of stimulating respiratory movements or of acting upon the beat of the heart.

Direct applications to the heart region do not readily affect the movements of that organ. If they do, the result is quite as likely to be harmful as useful. It is better, therefore, not to attempt it.

In order to act upon the respiratory centres the use of the induction coil, preferably with a long secondary wire and the metallic brush electrode, is advised. The region of the body which is stimulated is not of special importance; the applications may be made to any part which is exposed and convenient of access.

A considerable reflex effect is produced by this cutaneous stimulation, and if the dry brush and the long wire coil are used there is much less risk of producing fatigue or exhaustion of the patient, than if a short wire coil be used with moistened electrodes. Stimulation of the face, especially of the nose and upper lip, tend to act favourably upon respiration. Duchenne has shown that stimulation of this kind applied to the precordia or to the skin of the back in the lower dorsal region also influences the respirations. At the former situation inspiration is chiefly promoted, and in the latter expiration.

The phrenic nerves in the neck can be directly stimulated by the induction coil without difficulty, and contraction of the

* *University of Pennsylvania Medical Bulletin*, September, 1901.

diaphragm will follow. No inconvenience seems to be produced by the proximity of the vagi. The method is as follows: Two moistened electrodes of small size, about one inch in diameter, must be connected to the coil; one should have a key for making and breaking the circuit. These are to be applied under the posterior border of the sterno-mastoid muscles, which should be pushed forward. The key must then be closed and opened rhythmically about every two seconds; each closure causes an inspiration, expiration being allowed to take place during the intervals. This use of the induction coil to set up respiratory movements may be advantageously combined with mechanical artificial respiration by Silvester's method. Electrical stimulation of the phrenics in asphyxia and in chloroform-poisoning have been successfully carried out. Stimulation of the epigastric region may cause expiratory movements by acting upon the abdominal muscles.

277. **The Respiratory Organs.**—Statical charging has been recommended as a valuable application for strengthening the singing voice. Bordier mentions that M. Moutier, with the collaboration of M. Granier, of the Opera in Paris, had been able to prove conclusively that electrostatic applications had a favourable influence upon laryngeal fatigue (*fatigue vocale*). Their method consisted in charging the patient negatively, and in using a positive or grounded point electrode applied near to the nose and mouth. A brush made of straw (*chiendent*) seems to have been preferred to the ordinary form with metallic points. With daily applications lasting fifteen or twenty minutes, the observers noted an increase in the duration of the respiratory movements, the pitch of the laryngeal sounds was raised, and the sustained production of the higher notes was made more easy. The quality of the voice also acquired a more "mordant" character, and became more agreeable.

Electricity has also been used indirectly in the treatment of whooping-cough by ozonized air. The investigations of Bordier seem to show that the number of paroxysms of coughing may be notably diminished, and the duration of the illness shortened by administering an inhalation of ozonized air for ten minutes daily.

278. **Pulmonary Tuberculosis.**—The use of X-rays in the early diagnosis of phthisis has been much discussed in recent years. It will be sufficient to point out here that the permanent records

given by X-ray photographs of the chest are of the greatest value for observing the progress of a case. The detection of small discrete masses of tubercle in the apex of a lung by X-ray photography is by no means difficult, and the possible error of confounding old and calcified masses with recent and active ones can best be overcome by examinations repeated at intervals of time. In examining the chest by the fluorescent screen it is observed that the movements of the diaphragm are much restricted on the affected side, and this symptom is thought to be one of the earliest morbid appearances to be observed in cases of commencing phthisis.

Dr. David Lawson, in a paper on the results of treatment in 301 cases of phthisis by open-air methods, states that at Banchory it has been customary always to screen and to skiagraph the patients soon after admission, after having previously formed an opinion by a careful physical examination of the conditions present, and it has frequently been his experience to detect by this means conditions which had not been even so much as suspected previously to the X-rays being used. All chests were systematically examined by screening from time to time whilst patients were under treatment, and he had found observations so made on the subject of changes going on in the lesions a matter at once interesting, instructive, and helpful in the matter of treatment. The value claimed for the X-rays in the treatment of tuberculous glands had been fully confirmed by the observations made in the few cases which had come under notice. One case of lupus of thirty-six years' standing had cleared up under its use, and at the time of writing, over twelve months since the treatment was suspended, appeared to be quite well. The X-rays had also been applied in several cases of enlarged glands at the root of the lung. The results obtained in those cases, whilst not striking, have been at least encouraging.

H. Thiellé* has done much careful experimental work on the treatment of phthisis by high frequency, and his book is a monument of painstaking research. He takes the line that the respiratory exchanges are exaggerated in the tuberculous patient, either as a defensive reaction, as a consequence of the presence of the bacillus, or as a constitutional defect, whereas the gouty

* "Traitement de la Tuberculose par les Courants de Haute Fréquence et de Haute Tension, basé sur l'Étude du Chimisme Respiratoire," Rouen, 1905.

individual belongs to an opposite type, and, as has long been believed, has a constitution which strongly resists the tuberculous invasion. In order to treat a phthisical individual, therefore, one must endeavour to modify his respiratory exchanges, and to bring them to the normal values. In employing high-frequency currents this result can be more or less closely obtained, and the tendency to recovery goes hand in hand with the acquisition of normal characteristics, as Thiellé's figures show.

279. **The Digestive Apparatus.**—In dentistry electricity has been used for the sterilization of the septic roots of teeth. E. Zierler* claims that by these means the roots of exceedingly septic teeth, even when they are so tortuous or so small as to be inaccessible to ordinary methods of cleansing and medication, may be effectually sterilized at one short sitting. The apparatus employed is a Leclanché battery of 30 elements, with a rheostat and galvanometer, the current therefore being of comparatively high voltage; but the quantity is only small, not more than 1 to 3 milliampères. A platino-iridium needle is attached to the positive pole, and the negative terminates in an oval plate applied to the neighbouring gum or other convenient spot, the needle being passed as far up the root as possible. After the passage of a 3-milliampère current for ten minutes, the needle when withdrawn is found to be absolutely sterile, as is also the wall of the root canal; other portions of the root, and especially its exterior, may remain septic. This would appear to be in some sense a failure, but in practice it is seldom that the septicity of a root extends much beyond its canal and the soft parts immediately about its apex. Some patients cannot tolerate this amount of current, but the same results may be attained by a proportionately longer application of a weaker current. Salt solution is introduced into the root canal as far as it will go, but it may be doubted whether much of it will reach far down a small canal. The electrolytic introduction of cocaine for dental operations has also been found useful.†

280. **Œsophageal Spasm.**—Under the name of "œsophagism," Bordier defines this condition as a neurosis characterized by muscular spasm of the œsophagus, causing difficulty in swallow-

* "Behandlung putrider Zahnwurzeln," Würzburg, 1905.

† W. J. Morton, "Cataphoresis, or Electric Medicamental Diffusion," New York, 1898.

ing. Cases of this class who have troublesome dysphagia, but in whom the passage of a sound proves that no organic stricture is present, are not very common, but are seen from time to time. A patient of mine, a gentleman of middle age, was very much inconvenienced by this form of spasm. He complained that he was prevented from entertaining his friends at dinner because of the difficulty which he experienced in swallowing; even when taking a meal quietly at home with his family, he was much embarrassed by the same trouble. Pain was also felt, and was referred sometimes to the epigastric region and sometimes to the sternum.

On several different occasions a short course of treatment by positive static charging, with brush discharge to the neck, chest, and epigastrium, has dispelled the tendency to spasm, and has enabled him to eat with facility and comfort, the improvement lasting for several months after the suspension of treatment.

Bordier recommends the treatment of this neurosis by either direct or by induction-coil currents, applied externally to the neck and chest, and in more obstinate cases would apply currents directly to the œsophageal walls by means of a metallic bougie. In cases where a simple static treatment is successful these procedures will hardly be required.

281. **Stricture of the Œsophagus.**—Electrolysis has been recommended for stricture of the œsophagus by most writers on medical electricity. A bougie electrode is used connected to the negative pole of the battery. A bougie is selected of a size rather larger than the stricture, to which it is applied firmly. A current of five or ten milliampères is passed. After a variable time the stricture gives way, and the bougie passes through it. The time of each operation may be from ten minutes to half an hour. The operation is repeated with a larger instrument in ten days or a fortnight. No anæsthetic is required.

T. D. Savill* recently showed before the Clinical Society a case of traumatic stricture of the œsophagus relieved by electrolysis. The patient, a woman aged forty-nine years, in the year 1880 swallowed some vitriol by mistake. This was followed by extreme dysphagia and stricture, so that two years later a small bougie could only be passed with difficulty. After a time the difficulty in passing the bougie increased, and when the patient was seen in June, 1903, no bougie had been passed, nor had she

* *Lancet*, May 6, 1905.

swallowed solids for nine weeks, and fluids could only be swallowed with the greatest difficulty. Electric treatment was applied, and was quickly followed by improvement ; in six weeks she could swallow minced meat, and had gained seven pounds in weight. The improvement was maintained for eighteen months, when a relapse required a renewal of the electricity, and she could now take solids without having to pass a bougie.

Radium has been used in the treatment of cancer of the œsophagus by Max Einhorn.* The method which he employs is as follows : An œsophageal tube is provided with a style, and has fitted on to its end by means of a screw a capsule, partly made of vulcanite, and the upper part made of metal. This capsule contains the radium. The tube is dipped into warm water and passed, together with the style, until the stricture is reached. The style is then withdrawn, and the outer end of the tube fastened to the patient's ear. The instrument is allowed to remain in the gullet for half to one hour, according to the requirements of the case. After removing the tube, the capsule is unscrewed, and the small bottle containing the radium is taken out before the capsule, etc., is disinfected. The results of the treatment in seven cases were satisfactory. One patient, aged seventy-five years, had an obstruction 15 inches from the teeth, and could not even swallow fluids. He was treated for two and a half months, every other day for half an hour. His condition improved during the treatment, and at the end of it he could swallow fluid and semi-solid diet ; five months later he was still improved, and suffered no pain. The second case was somewhat improved as far as the passage of the bougie was concerned, and felt a little better in herself ; the third case lost all pain, felt considerably better, and could swallow more easily—a larger bougie could be passed ; the fourth case was objectively much improved, the bougie could be passed without obstruction into the stomach, and she could swallow fluid and some solid food ; the fifth case was also much improved objectively, and also as far as swallowing was concerned ; the sixth case was gaining in weight, could swallow solid food well, and the stricture had disappeared ; and lastly, the seventh case was practically uninfluenced by the treatment. In the last six cases the treatment was carried out for one hour each day. He considers that radium applications are valuable in œsophageal

* *Berliner klinische Wochenschrift*, No. 44A, 1905.

cancer, and although he does not speak of any definite cure of the disease, he feels justified in saying that the cases were greatly improved by the treatment.

282. **X-Rays in the Examination of the Stomach.**—Norman Dalton and A. D. Reid* have described a method of examining the stomach by means of X-rays and a flexible tube filled with subnitrate of bismuth. An ordinary stomach tube is passed once a day for two or three days to accustom the patient to its presence in the stomach. Then, the stomach being empty, and the patient lying on his back, the bismuth tube is slowly passed into the stomach while the epigastrium is watched upon the fluorescent screen. In a typical case the tube is seen to emerge from beneath the ribs to the left of the middle line, and descends to the greater curvature of the stomach to the left of the umbilicus. Then the point of the tube slides upwards to the right along the pyloric end of the greater curvature, while the stem becomes convex towards the left. When the point becomes arrested at the pylorus, the rest of the tube adapts itself to the greater curvature, and the photograph of it in that position represents the greater curvature. The umbilicus is marked out by a metal disc and the curve of the ribs by metal wire to provide landmarks. Photographs were shown with the tube in various positions, which severally indicated gastroptosis, gastrectasis, and malposition of pylorus due to adhesions, all verified at operation. The method enabled one to arrive at a diagnosis with great confidence.

The patient lay on his back on a canvas-topped couch, underneath which the X-tube was mounted on a double slide, which allowed movement longitudinally and transversely. The tube was enclosed in an opaque box with an adjustable circular diaphragm placed over a 3-inch aperture opposite the target, the smallest diaphragm being used that would include the required area. When the bismuth tube had been inserted as far as it would go, the patient was directed to hold his breath, and an exposure of from ten to twenty seconds was made, the plate being placed on the abdomen.

Holzknecht† describes observations on healthy and diseased stomachs by means of X-ray examinations made after the in-

* *British Medical Journal*, April 1, 1905.

† *Berliner klinische Wochenschrift*, January 29, 1906.

gestion of food containing considerable quantities of subnitrate of bismuth. It was found that much more satisfactory results were obtained if the observations were made directly by means of the fluoroscope than if photography was resorted to, because the phenomena produced were so varied in nature that continued inspection was necessary in order to obtain any insight into their import. One conclusion reached was that a stomach normal in size and position is very rarely seen. The normal type of stomach is rather small, and is so placed that the pylorus forms its lowest point. The form most often observed, on the other hand, is much larger, and through descent of the greater curvature exhibits a rise at the pylorus. The author explains the formation of this type of stomach by the almost universal relaxation and atrophy of the anterior abdominal muscles, induced by the habits of muscular inactivity of the present age. In this way the lower part of the abdomen becomes protuberant, and the pad of the intestines on which the stomach normally rests drops down a considerable distance. The extremities of the stomach being fixed, while it is to a certain extent deprived of its natural support, the organ, which was not constituted for the purpose of standing a strain of this sort, undergoes gradual dilatation in the direction of its long axis. In other words, this is the beginning of gastroptosis, a condition which usually receives attention only when present to a marked degree, whereas naturally all intermediate stages must also exist. The author describes the phenomena attending the filling of the stomach with food as visible on the fluoroscopic screen, and explains the manner in which observations of this sort may be used for the detection of non-palpable carcinomata. Owing to the infiltration of the gastric wall with the tumour masses, easily recognisable abnormalities in the behaviour of the stomach when bismuth food is poured into it can readily be detected. Its functional efficiency can also be tested by inclosing bismuth in tiny bags of gold-beater's skin, which are swallowed by the patient. As soon as the bag is digested by the gastric secretions the bismuth escapes, an act which is readily discernible with the fluoroscope. The author considers that this method is superior to the somewhat similar one of Sahli.

283. **Affections of the Stomach and Intestines.**—Electrical treatment may often be applied with advantage in certain affections

of the gastro-intestinal tract. Dr. George Herschell,* who has given special attention to this subject, states that by the employment of electricity in a proper manner a cure can be obtained in certain forms of dyspepsia associated with neurasthenic states, that hyperæsthesia of the gastric mucous membrane can be diminished, gastralgia and gastric myasthenia relieved or cured, and that constipation depending upon intestinal atony can be remedied.

In dilatation of the stomach the treatment by high frequency has been strongly recommended by Crombie and Bokenham. Herschell would distinguish true gastric dilatation from gastric myasthenia, and would expect good results from high frequency in the latter condition only.

High-frequency currents find their principal application in those cases of atonic dilatation of the stomach so difficult to treat successfully by other means, and yet so commonly met with in phthisical cases. They are of further value in the neurotic type of patient and also in the various neuralgias accompanying the anæmia present in phthisis.

Intestinal peristalsis can be set up by electrical currents applied through the abdominal walls, and chronic constipation can be permanently relieved by their use. The poles may be placed, one on the lumbar spine and the other on the surface of the abdomen; they should be of large size. The abdominal electrode should be moved over the whole surface of the belly for a period of five or ten minutes. After a few applications the bowels become more regular. Dr. Wahltuch† has reported seven cases in which the continuous current produced good results. His method was to use a large sponge for the positive pole, and an ordinary medium-sized one for the negative. The former was applied to the epigastrium, while the latter was slowly moved over the whole abdominal surface, in the direction of the intestinal canal from the duodenum to the sigmoid flexure, where it was finally fixed, and the current of from five to thirty Leclanché cells allowed to pass steadily without interruption for ten, twenty, or thirty minutes. The operation was repeated every other day for periods of from three

* "A Manual of Intragastric Technique," H. J. Glaisher, London, 1903. "Practical Lessons in the Treatment of Affections of the Gastro-Intestinal Tract by Electrical Methods." "Medical Electrology and Radiology," A. Siegle, London, 1904.

† *British Medical Journal*, 1883, vol. ii., p. 623.

to six weeks. The bowels gradually became regular in their action, although all aperients and enemata were stopped, and they remained so after the cessation of the treatment.

Many other writers have reported similar results, and I have myself obtained notably good results in some cases, though not in all.

Another plan which has been proposed for obstinate cases is to introduce a bougie electrode (Fig. 178) into the rectum, the other pole being kept on the abdomen as before ; and to avoid the risk of electrolysis and injury to the rectal mucous membrane, a combined douche and electrode has been devised, and in France a number of cases have been treated for obstinate constipation in this way with success. It has even been used for cases described as intestinal obstruction. It is obvious, however, that the nature of the intestinal obstruction should be fairly well made out before undertaking to treat it by electricity.

An interesting article on this subject by Dr. Larat, of Paris,

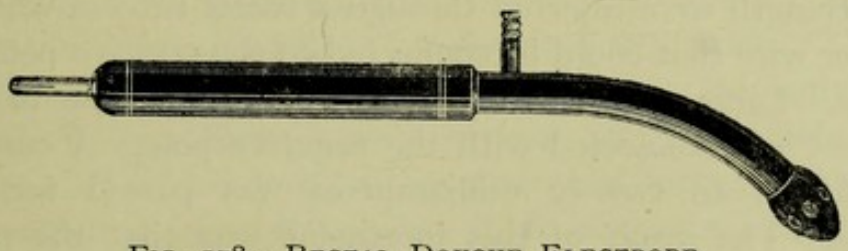

FIG. 178.—RECTAL DOUCHE ELECTRODE.

will be found in Bigelow and Massey's "International System of Electro-Therapeutics."*

Dr. George Herschell recommends the use of three-phase currents (§ 92) for the treatment of constipation due to atony of the walls of the rectum, and enumerates several arrangements of the three electrodes. In one plan two are placed upon the back, one along each side of the vertebral column, and the third is applied to the epigastrium. In another, a rectal electrode is used, and consists of a bag of membrane surrounding a metallic tube which acts as conductor and also permits of the filling of the membrane bag with water after it has been introduced into the rectum. The second electrode is placed beneath the back, and the third is moved over the abdominal surface. The use of a membranous bag containing fluid in place of a continuous douche presents obvious advantages, as has been pointed out by Dr. Herschell.

* Henry Kimpton, London, 1894. Second edition.

284. **Mucous Colitis.** — This affection is sometimes very notably benefited by general electrization, and the electric bath with sinusoidal current may be tried with advantage. Doumer has found that direct current applied to the abdomen by means of two large electrodes placed in the iliac fossæ has proved valuable in relieving the constipation associated with this condition. Currents from 30 milliampères upwards are used, and reversals are made every minute, the whole time of the application lasting eight or ten minutes.

Laquerrière and Delherm have confirmed Doumer's observations, and consider the results obtained to be brilliant. They report twenty-two successful results out of twenty-five cases treated.

J. C. Webb* has advocated the use of electric enemata of silver nitrate in colitis, and has reported a case in which the treatment was followed by good results. After a preliminary lavage of the bowel, one and a half pints of a silver nitrate solution of 0·1 per cent. strength were injected through a rectal tube in which was a copper wire that could be connected to the positive pole of the battery. Large clay electrodes were placed on the back and abdomen and connected with the negative pole. A current of from fifteen to twenty milliampères was passed for fifteen minutes. The result of this treatment was that the motions became natural in consistency and frequency, that the mucus disappeared and the flatus diminished. He considered that there was an introduction of the ions of silver into the cells of the mucous membrane, and attributes his success in part to their influence.

285. **Affections of the Rectum.**—Electricity has been employed in various morbid conditions of the rectum and anus. In paretic states of the sphincter and in prolapse the application of induction-coil currents has been found useful by some writers, and the direct current has been applied with equal success by others.

In pruritus ani the static brush discharge, the effluve of the high-frequency apparatus, and the Röntgen-rays are all efficacious methods of treatment.

In the treatment of some cases of piles, and of fissure of the anus, high-frequency applications are very successful. The method of application is to use a conical electrode of bare metal; this is anointed with vaseline and introduced into the anus, and

* *Lancet*, November 4, 1905.

daily applications of two or three minutes' duration are given. The patient should lie on the condenser couch (§ 141). In the case of piles the results appear to have been least satisfactory when the state has become chronic, with well-marked structural changes in the mucous membrane.

In the case of rectal fissure the same electrode as that employed in piles may also be used, or one of the glass vacuum electrodes figured on p. 237. In either case they should be of sufficient diameter to stretch the folds of mucous membrane, in order that the effluve or current may touch the fissure itself.

Bokenham* has reported on 118 cases of piles and allied conditions treated by high frequency. He states that with metal electrodes currents up to 400 or 500 milliampères can be employed, but with the glass vacuum electrodes a magnitude of 150 should not be exceeded. His results are decidedly favourable, and in his paper the numbers cured or not cured are classified in accordance with the anatomical changes present.

286. **The Urinary Organs.**—Incontinence of urine is a symptom for which much can be done by electrical treatment. The cases of this complaint which are met with form several distinct groups. In one, there is want of tone in the sphincter of the bladder, and urine is expelled involuntarily during any muscular effort which involves the action of the abdominal muscles. In another group of cases occurring in women there is irritability of the bladder, and this discharges its contents with pain and spasm at frequent intervals, while in a third well-known form of incontinence the muscular apparatus is normal, but the bladder empties itself spontaneously during sleep.

In women it is extremely common for there to be some inefficiency of the former kind, and in consequence a little urine is apt to be expelled from the bladder during muscular effort such as lifting a weight or during coughing or sneezing. If the weakness of the sphincter be rather more pronounced the incontinence becomes troublesome, and advice may be sought. The weakness of the sphincter may also be due to some dilatation or injury of the urethra—for example, during parturition or after a digital examination of the bladder. The tone and power of the female urethra can be strengthened by electrical applications, and the patient's comfort may in this way be greatly increased. I have notes of several patients who suffered from

* *Lancet*, July 2, 1904.

incontinence of this kind, for which they were obliged in the daytime to wear a urinal apparatus, and were always wet and uncomfortable, and in whom a course of electrical treatment was completely successful. In one instance, the incontinence was the result of an operation upon the urethra for the removal of a caruncle. Since the operation the patient had been unable to hold her water, which escaped during any muscular exertion. After four or five weeks' treatment she was able to lift and carry her baby, and to play tennis, without any leakage from the bladder. Other cases of weak sphincter in which electrical applications have given great relief are those in which the trouble has come on as the result of a long railway journey without any opportunity of passing urine.

Even when the incontinence is part of a paraplegic condition, treatment applied to the bladder may be of service. I have notes of two women who received injuries to the spine through jumping out of windows. They were referred to me for electrical treatment for their incontinence, and in both the power of the bladder seemed to be improved by treatment. At the same time they were and had been improving generally before coming under my care, and therefore the results of the electrical treatment they received are not so conclusive. Bladder weakness in tabes sometimes undergoes decided, if temporary, improvement from electrical applications to the lower spine and perineum.

The condition of irritability of bladder which produces frequent calls to urinate is one that is commonly confounded with nocturnal incontinence.

There is a class of patient with so-called nocturnal incontinence in whom careful questioning will reveal the fact that there is not only a tendency to wet the bed at night, but also a weakness by day. These cases occur almost exclusively in females. When up and about they are unable to retain their urine with comfort for more than half an hour or an hour. If after the lapse of that time they have no opportunity of emptying the bladder voluntarily, pain and spasm come on and the urine is expelled. At night, too, they are obliged either to get up frequently, or else to wet the bed. In hospital out-patient practice patients of this type are usually in a wet condition locally, and their clothing smells of urine, whereas true cases of nocturnal incontinence are not so.

No electrical treatment seems to have the slightest good effect

upon the cases just described, and it is therefore very important before giving a prognosis to distinguish them from cases of true nocturnal incontinence, in which electrical treatment answers admirably.

287. **Nocturnal Incontinence.** — This affection has a totally different pathology to that of the kind of incontinence already discussed. In nocturnal incontinence the patients are able to retain their urine in a perfectly natural manner so long as they are awake, but when asleep the bladder has a tendency to empty itself without awaking them. The condition is due to a persistence of the infantile mechanism of micturition, and the bladder acts during sleep in an automatic way, the controlling centre in the brain not being strong enough to maintain its action during the condition of sleep. The education of a child includes the education of inhibitory centres which bring the reflex mechanisms of micturition under the influence of the will, so that the action of the bladder in adult life is continually controlled. If the control be imperfect the bladder may empty itself whenever the higher centres are in abeyance, as during sleep. If sleep passes into coma, the controlling centre falls into abeyance in any case. A person suffering from nocturnal incontinence may pass water unconsciously in the daytime when asleep in a chair. As a rule sleep is very sound in patients who are the subjects of enuresis nocturna.

Electricity is of use in enuresis nocturna because it is able to stimulate the centres, both cerebral and spinal, by producing painful local impressions which tend in time to bring the inhibitory cerebral mechanism into more close relation with the reflex centres in the lumbar cord.

It is important to try to combat the tendency to very deep sleep which exists in many of these patients. This may be attempted in various ways; for example, the number of the bedclothes should be reduced so that the patients are a little chilly at night; and a clock which strikes the hours is also a useful thing to have in the bedroom, epecially if the patient can be taught to awake when the clock strikes twelve or any other hour which may be specified. They must be taught to practise retaining the urine as long as possible by day, so as to accustom the bladder to become more tolerant of its contents, and to augment the influence of the inhibitory centres by this exercise of their functions.

In children with enuresis nocturna it is important to search for any reflex irritation and to remove it when possible. Thus worms, oxaluria, a narrow meatus, or phimosis, if present, must be dealt with before resorting to electrical treatment.

The results of treating nocturnal incontinence by electrical applications are very good. Most of the cases can be cured by attention to the points just enumerated.

The best mode of application for cases of incontinence with weakness of the sphincter in women and girls is to introduce a bare metal sound into the urethra as one electrode, and to place the indifferent electrode upon the lower dorsal region of the back. The sound must not enter the bladder for more than a very short distance, otherwise but little current will pass to the walls of the urethra.

For male patients applications to the perineum will usually answer almost as well as the passage of a sound, and the latter

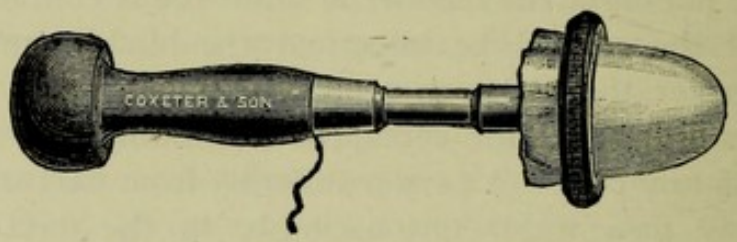

FIG. 179.—ELECTRODE FOR ENURESIS.

may, therefore, be reserved for the more troublesome cases; the use of a perineal electrode makes the operative procedure more simple and less formidable to the patient. An electrode of suitable shape consists of an acorn-shaped piece of metal fitted with a handle, and it is so contrived that a chamois-leather cover can be adapted to it in a moment for each application. A ring of vulcanite pushed on over the piece of leather serves to hold the latter in place.

The currents used must be decidedly painful, in order to produce a suitable impression upon the nerve centres. It is useless to undertake the electrical treatment of incontinence without direct applications to the perineal region, and consequently it is very important not to allow incontinence of urine in children to be left untreated in the hope that they may outgrow it, because in girls after puberty the local applications may be a source of embarrassment. Where it is desired to avoid all manipulations of these parts the treatment may be carried out by applications

in an electric bath, using a small metal electrode pressed up between the thighs, outside the bathing dress, in place of the ordinary foot-plate. The current then passes as desired into the perineal area.

In the treatment of incontinence of urine the induction coil applied strongly for eight minutes, and followed by a battery current of five to ten milliampères with reversals every five seconds for three or four minutes, seems to give the best results. The constant current without reversals should not be used for fear of injuring the skin and mucous membrane through electrolytic action.

288. **Stricture of the Urethra.**—Modern writers on this subject refer to Crussel, 1839, as the first to use electrolysis for the cure of this condition, and to Mallez and Tripier* as the first to practise it systematically.

The electrical treatment of any disease, in order to justify its existence, must offer results which are superior to those which can be had in other ways, and apparently surgeons do not find it necessary to use electrolysis in stricture of the urethra because they can obtain the required results without it.

In a paper read at the annual meeting of the British Medical Association, in 1886, by the late Dr. W. E. Steavenson, the following account of electrolysis of stricture occurs :

" For the treatment of stricture of the urethra, the electrodes are catheter-shaped gum-elastic bougies, ending in a metal nickel-plated piece connected to a binding-screw on the handle. The indifferent electrode is placed upon the patient's back if he is in the recumbent position, or it may be placed on any other convenient part of the body.

" An ordinary bougie is first passed down to the stricture, and by its means the distance of the stricture from the meatus is ascertained, and a mark made on the bougie. It is then found out what sized bougie will pass the stricture. Say, for instance, it is ascertained that a No. 3 bougie (English) will pass ; a No. 5 electrode is then taken and passed down to the stricture, where it is arrested. It can be made certain that the electrode is arrested at the stricture by previously marking it, after measurement and comparison with the bougie first passed. When the electrode is in position against the stricture, it is connected with

* " De la Guérison durable des Rétrécissements de l'Uréthre par la Galvano-caustique Chimique," Paris, 1867.

the negative pole of the battery, the circuit is closed, and the current gradually increased without breaks until the maximum strength is reached that it is intended to employ, namely, about five or six milliampères. The electrode is kept gently pressed against the stricture in the direction of the ordinary course of the urethra. No force is used, but the current is allowed to do the work. The surgeon has to keep his attention applied to the electrode, so as to guide it in the right direction, otherwise a false passage may be dissolved into the side of the urethra. Therefore skill in passing a catheter is a requisition. In the hands of a surgeon who knows his way into the bladder, a false passage is not more likely to be produced than is the case in passing an ordinary catheter. By the dissolution of the obstacle in front of it, the electrode slowly passes into the bladder. The current then should immediately be cut off, and the bougie withdrawn. The duration of the operation depends upon the density of the stricture and the strength of the current used."

The subject of electrolysis for urethral stricture still receives a certain amount of attention from individual operators.

289. **Sexual Disorders.**—Various morbid conditions of the male sexual organs have been treated by electricity.

For impotence and sexual debility Erb has advised that a small button-shaped electrode connected with the positive pole be held to the perineum, and another larger electrode (negative) be moved slowly up and down the lower dorsal and lumbar spine. The current may be of from five to ten milliampères, according to the tolerance of the patient, and the time occupied may be ten minutes. Applications daily for a week, then every other day. In this way the symptoms may be dispelled. Local treatment by means of the wire brush has also been proposed for sexual debility. Electricity is in no way a sovereign remedy for this class of patient, and unless something can be done by enjoining abstinence, the restoration of lost sexual powers is generally a vain hope, except where the troubles are mental rather than physical. Even then medical treatment cannot do very much.

In varicocele the pain is said to be relieved by applications of direct current if the scrotum is immersed in a small bowl of warm water connected to the positive pole; the negative pole is applied to the inguinal region or over the sacrum.

290. **Prostatic Enlargement.**—X-rays have been successfully

used in this disorder. Caracelli and Lucaselli* report two cases of enlarged prostate in men over sixty which were much improved by X-ray treatment. The improvement was, moreover, maintained when the patients were seen a year later. The *modus operandi* was to place the patients in a suitable position, protecting the scrotum, penis, and thighs by means of a lead plate, and then to apply the rays to the perineum at 20 to 25 centimetres distance for about ten minutes at a time for two and three times a week, then every fortnight. Under this treatment the urine cleared, the flow of urine was improved, and the frequency of micturition lessened. The authors consider it unnecessary to pass the tube up the rectum, as the rays would act equally well when applied externally in the method used by them.

Moszkowitz also has used X-rays for enlarged prostate. Of three men who were treated, the first was sixty-six years old, and after three exposures, each lasting fifteen minutes, he was able to pass urine spontaneously. The second patient was seventy-seven years old, and his prostate was enormously enlarged and very hard. The same treatment was adopted, with the result that he could pass urine freely, though some of it was still retained. The third patient was completely cured. Two of them had severe hæmorrhagic cystitis, and one had epididymitis after seventeen days. It was difficult to say whether these complications were the effects of the rays. As regards the technique, a rectal speculum was used, and the surrounding parts were covered by lead.

Léron† has reviewed the literature of the Röntgen-ray treatment of hypertrophy of the prostate, and finds that in general it shows very favourable results.

291. **Orchitis.**—Scharff‡ claims to have employed electricity successfully in the treatment of epididymitis. He does not wait until the affection has become chronic, but immediately and during the acute stage applies the anode to the lower part of the scrotum. The patient being in the dorsal position, a large electrode with a maximum current of half a milliampère is employed, the duration of the application being three minutes on the first occasion; this is afterwards increased to five and ten

* *Gazz. degli Osp.*, January 18, 1905.

† *La Clinique*, April 13, 1906.

‡ *Centralbl. f. Krankh. d. Harn und Sex. Organe*, 1, 1894.

minutes, the increase being very gradual. The weak constant current thus employed should be carefully gauged with a sufficiently sensitive galvanometer, and the current closed insensibly with the aid of a rheostat. No unpleasant sensation should be thus produced, but the patient will subsequently on palpation be able to observe a considerable diminution or total disappearance of the tenderness which had previously existed. While in the same position a suitable suspender is applied, and the patient then allowed to walk about. Towards the seventh day the current can be increased to three milliampères, the same electrode, however, being still used for a few days, when it can be somewhat reduced in size. The kathode is placed above the groin and on the abdominal wall. By this treatment, rest in bed can usually be dispensed with, the other advantages over the older methods being rapid and marked relief of the pain from the first, and greater rapidity in the disappearance of the swelling. Onimus also speaks very favourably of the good effect of electrical treatment in orchitis, and Picot, of Tours, has reported good results in forty cases; both used currents of about five milliampères.

Dr. Duboc,* of Rouen, has reported two cases of chronic orchitis and epididymitis following gonorrhœa treated successfully by electricity; one had lasted for eighteen months in spite of much medication, the other for nine months. In both cases the swellings disappeared rapidly and completely after about six applications. Two pads were used, one in front of the testicle and one behind; both were moistened with a twenty per cent. solution of iodide of potassium and a continuous current of twenty milliampères was used for ten minutes.

292. **Diseases of Women.**—Electrical methods are largely made use of in gynæcological practice, not only for their direct effects, but also for electrolysis, and the galvano-cautery. Much attention has been directed to the subject of the electrical treatment of fibromyoma, and an immense amount of literature has been produced since the introduction of Dr. Apostoli's method of treating that complaint by electrolysis of the uterine mucous membrane.

In pruritus of the vulva, in vaginitis, and in vaginismus, various electrical procedures may be adopted with success. In the former the brush discharge of the static machine or high-

* *Archives d'Électricité Médicale*, 1894.

frequency apparatus gives relief. The best way of applying the latter is by means of a glass (condenser) electrode.

The use of electricity in diseases of women is so much a matter for the gynæcologist himself that a few brief notices of the different conditions in which electricity can be simply applied will suffice in the present work. Those wishing to study the subject more fully should consult the works of Apostoli, and of his followers. In the "International System of Electro-Therapeutics" of Bigelow and Massey, a considerable amount of space (nearly 250 pages) is devoted to this section of electro-therapeutic work, and may be referred to with advantage.

Dr. Margaret Cleaves* has advocated the use of a douche electrode like that shown in Fig. 180 for electric applications to

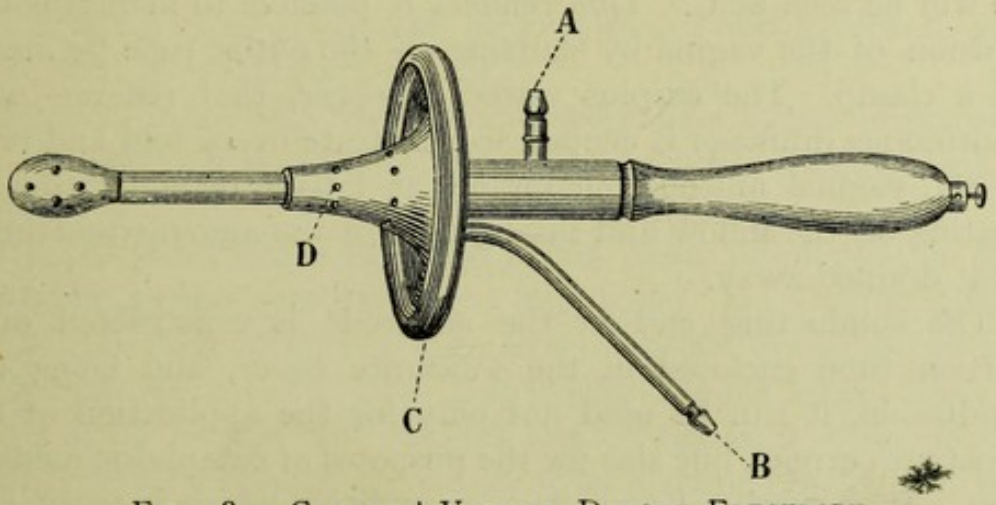

FIG. 180.—CLEAVES' VAGINAL DOUCHE ELECTRODE.

A, inlet; B, outlet; C, collar of soft indiarubber; D, perforations for outflow.

the female genital apparatus. By the addition of a soft rubber collar it can be made to enclose the external parts, and to act as a partially watertight cap, thus permitting of slight distension of the mucous membrane, and a penetration of the fluid into its folds and interstices. She has found applications by means of this electrode to be valuable in the treatment of pelvic exudates, ovaritis, vaginitis, eczema, and pruritus of the vulva, and prefers it to all other forms of electrode.

The external part of the electrode is of hard rubber, with a binding-screw and two tubes to act as inlet and outlet respectively. The shield *D* is movable, and has two rows of perforations through which the surplus water drains into the tube *B*. To this drainage-tube is affixed a few feet of rubber hose, of less

* *Medical Record*, August 25, 1894.

diameter than that on the fountain syringe through which the water or the medicated solution gains entrance into the vagina, in order to retard the drainage and keep the vagina distended during the time of administration of the current. This drainage hose is dropped into a jar at the foot of the operating-table, the syringe-hose is attached at *A*, and the vagina allowed to become well distended with the water or medicated solution before the current is turned on. By firm and even pressure of the shield over the ostium vaginæ, with the labia folded out, so as to occasion no discomfort to the patient, it is possible to administer any quantity of the douche (1 to 3 or more quarts) without getting a drop upon the patient's clothing.

A cushion of soft rubber is placed over the edge of the shield, as will be seen at *C*. This renders it possible to maintain distension of the vagina by shutting off the outlet tube by means of a clamp. The surplus water, however, that remains with continuous drainage is enough to penetrate every fold and rugæ of the vaginal mucous membrane, as I have demonstrated by cutting off the inflow and taking note of the amount remaining as it drained away.

The conducting end of the electrode is constructed of a carbon tube enclosed in the vulcanite cover, and being unoxidizable, it can be used not only for the application of the constant current, but also for the purposes of cataphoric medication. In gonorrhœal vaginitis—a condition which is recognised as extremely difficult to treat—it will be possible by this method to bring not only the os and cervix uteri, but every interstice of the vagina as well, under the influence of the medicated solution and thus to combat the specific condition. The fact that the gonococcus penetrates the submucous structures makes it very desirable that we should be able to apply our remedies in such a manner as to insure their destruction. By cataphoric medication this is possible, as the medicament not only comes in contact with the mucous membrane, but is caused to penetrate more or less deeply into its structure according to the strength of the current and the length of the application.

By means of anodal diffusion, a solution of sulphate of copper of requisite strength could be used to advantage in gonorrhœal cases. In the later stages of gonorrhœa, in conditions of pelvic congestion, uterine catarrh, and in some leucorrhœas, hydrastine thus diffused would be of much greater efficacy

than in its ordinary administration by the mouth, or by means of vaginal injections. Bichloride of mercury in solution could also be used according to the indications, and in strength of from 1 to 1,000.

293. **The Mammary Glands.**—Electrical stimulation applied to the mammary glands has been found useful for promoting the secretion of milk in nursing women.

Two patients who were suckling their infants were treated in this way in the Electrical Department at St. Bartholomew's Hospital for failure in their milk-producing powers. In one case a decided improvement followed. In the other the results were doubtful. It is not often that the advice of medical men is sought for producing an increase of the mammary secretion.

Successful cases are quoted by Drs. Beard and Rockwell, and by several recent French writers.

Electricity has also been recommended as a means of increasing the size of the breasts in cases where their development is defective.

294. **Amenorrhœa.**—Electricity has been employed in the treatment of this condition for a long time. Dr. Golding Bird* had a very high opinion of the value of shocks from the Leyden jar for curing this symptom, and writes at some length upon it in his little book. His method was to transmit through the pelvis twelve shocks in succession from a small Leyden jar, the discharge being directed from the sacrum to the pubes. The induction-coil current applied to the uterus has also been found efficacious by Panecki and others in patients with amenorrhœa from sluggishness of the uterine functions apart from chlorosis. The electric bath, by its effect upon nutrition, acts as an indirect emmenagogue in chlorosis (§ 200). When this condition is present general treatment is usually sufficient, and local applications are not called for, and indeed are undesirable.

In healthy women in whom menstruation is regularly performed, electricity may certainly hasten the appearance of the flow, especially when it is applied to the abdomen or pelvic region. The electric bath may have the same effect.

It is best to suspend general electrical treatment in women for a few days before the menstrual periods, otherwise the flow may be rendered excessive, and in pregnancy it is better

* Golding Bird, "Electricity and Magnetism," 1849, Lecture V., and Appendix B.

not to employ electricity at all for abdominal or bladder troubles.

295. **Dysmenorrhœa.**—The effect on painful menstruation of the statical breeze has been referred to in § 192. It is a mode of treatment which is easy, and gives good results in many cases, using the positive charge with the negative breeze to the loins and spine. It is not a disagreeable form of treatment, and it should be given daily for a week before the date of the appearance of the menstrual flow.

296. **Ovarian Neuralgia.**—The abdominal pains felt by women and referred to a tender ovary may be treated by electricity. By some writers these pains are regarded as an expression of a general condition rather than as a sign of local disease, and on this ground the treatment advised is that of general electrization. Local treatment by direct current may also be employed successfully if large currents and long applications are used. Currents of 40 or 50 milliampères applied by means of large electrodes, placed one on the front of the abdomen and one at the corresponding part of the back, are recommended.

297. **The Vomiting of Pregnancy.**—Drs. Gautier and Larat* have described a series of cases, eleven in number, in which the battery current, stabile, arrested obstinate vomiting of this kind. The positive pole should be applied above the clavicle between the attachments of the sterno-mastoid muscle, while the negative pole is placed at the epigastrium. The current should be of eight to ten milliampères turned on and off very gradually, and continued for fifteen minutes. It may be applied several times daily in severe cases. In from 24 to 48 hours from the first application the vomiting was either greatly alleviated or had ceased entirely. Bordier and Verney have also published favourable results obtained in this manner.

298. **In Parturition.**—In a paper read by Dr. Kilner before the Obstetrical Society,† the use of the induction-coil current is advocated during parturition as a means of provoking or of strengthening uterine contractions. Sometimes the resulting contractions were very severe and prolonged, indicating possible risk to the child. The applications seemed to diminish the pains felt during the labour, and after the birth of the child

* "Traitement par l'électricité des Vomissements Nerveux, et en particulière des Vomissements incoercibles de la Grossesse," Paris, 1895.

† *British Medical Journal*, April, 1884.

ensured a firm uterine contraction, and much diminished the risk of post-partum hæmorrhage. Some medical men speak very highly of its value in childbirth, and make a practice of carrying a small induction coil in their obstetric bag. It has also been of service in flooding after miscarriage.

It follows that caution is necessary before applying electrical treatment to the abdomen or pelvic organs of a pregnant woman. An early writer speaks of having produced a miscarriage as the result of Leyden-jar shocks applied in this way.

P. Robecchi* has suggested the use of an electric sound for the induction of labour, or for stimulating the interior of the uterus, and he states that by suitably arranging the periods of stimulation and of rest it is possible to start uterine contractions of a rhythmic character which closely resemble those of a naturally contracting uterus.

299. **Electrolysis of Uterine Fibroids.**—Since the publication by Apostoli of his method of treating fibro-myoma, an immense amount of literature has been produced on the subject. Much has been said both for and against his treatment,† and the enthusiasm which was at first shown in its favour by many writers has to a large extent been followed by a reaction. There is no doubt that electrolysis may hold a place in the treatment of fibroids, because in many cases it affords great relief to the symptoms of the patient, even if it does not effect a radical cure of the disease. What has been written above of electrolysis in stricture of the urethra applies also to the electrical treatment of fibroids—namely, that the electrical method competes with other surgical modes of treatment without offering any decided advantages, and in consequence it is of secondary rather than of primary importance.

In 1882 Apostoli communicated a paper to the Académie de Médecine, in which he described his method of procedure. He recommended an internal positive electrode of platinum, and an abdominal electrode (negative) of moist china clay of large surface, and a continuous current of sixty to seventy milliampères, applied for from five to fifteen minutes. Sittings were repeated once or twice a week.

The action of the current was to produce destruction of the

* *Giorn. dell. R. Accad. di Med. di Torino*, December, 1903.

† See the medical journals, 1888, 1889, and publications by Drs. Steavenson, Bartholow, Keith, Massey, Engelmann, and many others.

uterine mucous membrane. The results were to reduce the size of the uterus, and to decrease the hæmorrhage. The destruction of the mucous membrane is followed by a healthy process of repair, by a process of involution, and by a cicatrization which checks the metrorrhagia.

Bergonié and Boursier have published the notes of a hundred cases in which they carried out Apostoli's treatment for fibro-myoma, and they give the following summary of their views: "The electric treatment of fibro-myoma is undoubtedly efficacious as a palliative method of treatment. When hæmorrhage was the chief symptom complained of, 90 per cent. were relieved. The general state of health was improved in 79 per cent., the symptoms of pain was relieved in 50 per cent., while a decrease in the size of the tumour was observed in 10 per cent. only."

CHAPTER XV

THE SPECIAL SENSES—THE SKIN

Ocular affections—Nerve deafness—Tinnitus aurium—The removal of hair—Alopecia—Ringworm—Sycosis—Acne—Furuncle—Nævus—Psoriasis—Eczema—Keloid—Lupus—Mycosis fungoides.

300. **Ocular Affections.**—Valuable results may be obtained by the treatment of corneal opacities by the continuous current. Alleman* states that he is convinced, from the observation of a number of cases extending over a considerable time, that the use of electricity promises the only treatment of value in this condition. He applies the kathode to the cocainized cornea, using as electrode the end of a silver rod, seven millimetres in diameter, with one-half to four milliampères for one or two minutes.

Several experimenters in this country have confirmed these observations. Synechiæ have also been frequently observed to fade and disappear under applications of the battery current through the closed eyelids. P. Pansier has also advocated the method, and has published notes of twenty-four cases.†

Certain rheumatic affections of the eyeball may also be treated by means of an electrode applied over the closed eyelid. Cases of scleritis and episcleritis, usually regarded as rheumatic affections, may be treated by applications of the negative pole through the closed eyelids, a current of from five to ten milliampères, according to the toleration of the patient, being given for five or ten minutes (Leduc).

301. **Xanthelasma Palpebrarum.**—Electrolysis is useful in this condition. The negative pole should be used, and the electrode should be a steel needle. The patch may be treated by holding the needle vertically and electrolyzing it all over with a succession of punctures.

* Bigelow and Massey, "An International System of Electro-Therapeutics." Kimpton, London.

† *Archives d'Électricité Médicale*, 1894. See also by the same writer, "Electrothérapie Oculaire" (A Maloine: Paris, 1896).

Villard and Bosc,* in writing on this subject, have given the following account of their method: The treatment is carried out at one sitting. For small plaques of 4 mm. or 5 mm. a single puncture only is required; for larger ones, the patch is divided into areas which are successively punctured. The important point is to neglect no part, and even to go slightly beyond the limits of the diseased area. The needle (Fig. 183) is inserted into the skin of the plaque parallel to the surface for a distance not exceeding 10 mm., and the current is slowly increased to six or eight milliampères. After two to four minutes it is gradually reduced again to zero.

During the electrolysis the skin of the plaque becomes greenish in colour, while the needles are surrounded by a frothy zone. The electrolyzed skin forms a superficial slough, which comes away eight to fifteen days later. A scab then forms, which falls off two or three times before cicatrization is complete, about three or four weeks later. As the result the xanthelasma disappears, and a smooth cicatrix remains.

302. **Lachrymal Obstruction.**—W. W. Jessop and W. E. Steavenson† have given an account of ten cases of lachrymal obstruction treated by electrolysis. The advantage of the method is due to the ease with which the action can be confined to the exact parts needing treatment. The instrument used by them is a curved platinum probe. The operation is simple; the current required is small, two to four milliampères being sufficient, and the duration is thirty seconds. No anæsthetic is needed; the probe must always be negative, the positive pole being the usual pad indifferent electrode. Two or three sittings suffice to produce cure of the obstruction. The cases related are confined to those in which the obstruction was at the punctum or in the canaliculus, and not in the sac itself. The operation is simpler than the slitting up of the canaliculus, and the improvement is permanent.

303. **Trachoma.**—S. Mayou‡ has treated this condition by X-ray applications. In his cases the affected eyelid was everted, and a two-minutes' exposure given on four to six successive days, and this was repeated after a few days' rest. Twelve or fifteen applications were needed to effect a cure. Where one

* *La Clinique Ophthalmique*, 1903.

† *British Medical Journal*, 1887, ii., p. 371.

‡ "The Uses of X-rays in Ophthalmic Surgery," *Archives of the Röntgen Ray*, vol. vii., p. 61, January, 1903.

eye only was treated, while the other was shielded from the rays, the cure was confined to the treated eye.

Bishop Harman* considers that X-rays present no advantage over the ordinary treatment with sulphate of copper. It is probable that a brief electrolysis of each nodule with a copper needle attached to the positive pole of a battery of 3 or 4 cells would prove effective. Radium has also been used in trachoma, and good results have been claimed for it.

304. **Optic Neuritis and Atrophy.**—Electrical applications of continuous current have been used for optic atrophy and optic neuritis, and several cases have been reported in which improvement of sight has followed. When atrophy comes on without previous optic neuritis, the prospects are considered less favourable. The treatment is by transverse currents through the temples, with reversals, and by longitudinal currents through the head, with the anode over the closed eyelids.

The prospects of improvement depend much upon the nature of the disease. In tabetic atrophy, good results could hardly be expected, but Capriati† recommends a trial of the method, and considers that he has obtained improvement by using currents of two milliampères applied longitudinally. His views have been summarized as follows : Electrical treatment is indicated in tabetic atrophy of the optic nerve in cases in which the disease is not running a very rapid course, and before it has reached a very advanced stage. If employed in the early stages it appears to do good, and, with certain limitations, tends to arrest the morbid process, apparently by acting on the nerve fibres still unaffected. Better results may be anticipated from the application of the current antero-posteriorly than transversely, although neither method has yielded results warranting great enthusiasm. In neuritis affecting the nerves of special sense we usually have to deal with a progressive and degenerative state, and on this account treatment does not give results like those which may be expected to follow simple traumatic lesions of the ordinary mixed nerves.

Ludwig Mann‡ has also seen occasional benefit follow electrical applications in ten cases of atrophy and retrobulbar neuritis.

* *British Medical Journal*, August 26, 1905.

† *Riforma Medica*, October, 1893. Abstract in Weekly Epitome of *British Medical Journal*.

‡ *Zeitsch. für Diät und Physik. Therapie*, November, 1904.

In retinitis pigmentosa and in certain other retinal conditions (syphilitic neuro-retinitis, retino-choroiditis) it appears that a favourable effect may be produced by applications of continuous current. M. Gunn* has recorded 18 cases of optic nerve atrophy, of which 6 were improved, 4 were doubtful, and 8 were not benefited. He concludes that the prognosis is best in young or middle-aged people, with recent failure of sight, and ability to count fingers at least. In retinitis pigmentosa the results were much more encouraging. Of two cases under his own care, and of two others, he reports that "all were improved."

305. **Auditory Nerve Deafness.**—The treatment of nerve deafness by electricity sometimes gives good results.

The auditory nerve can best be tested or stimulated by a bifurcated electrode, which can be applied to both ears at once. By proceeding in this way there is less likelihood of making the

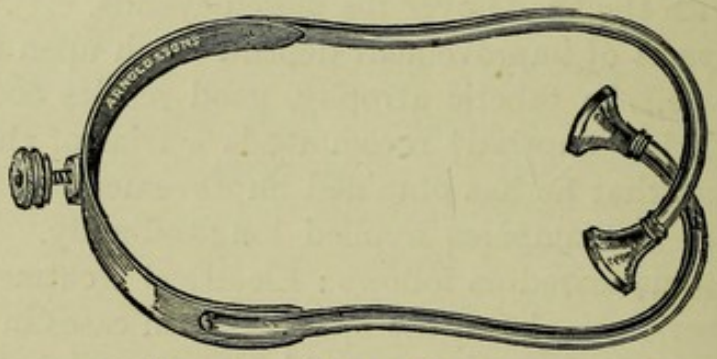

FIG. 181.—AURAL ELECTRODE.

patient giddy (§ 180). The continuous current should be used, with the negative pole to the ears. The current should be caused to vary gradually during the whole time of the application, either by using a rhythmic interrupter, or by turning the current on and off by hand with the current collector. The strength should not exceed ten milliampères. The patient must be watched for signs of faintness, as this may be produced if the currents are too strong. The application may be for ten minutes.

An inch is a suitable diameter for the electrode surfaces. If they are less than this some soreness of the skin may be produced at the points of contact from electrolytic action. A small pad of moist absorbent wool placed between the electrode surfaces and the skin improves the contact. These precautions are necessary because the electrodes are so small, and the density of current is consequently great.

* "Royal London Ophthalmic Hospital Reports," vol. x., 1881.

By persevering with this treatment many patients will experience decided improvement, and a good effect may even follow the first applications, and the result may be lasting. Intelligent patients can be taught how to carry out treatment for themselves, and should be encouraged to persevere for one or two months.

306. **Tinnitus Aurium.**—Subjective noises in the ears can often be relieved by a course of treatment with continuous currents in the manner described in the preceding section.

Tinnitus complicates nearly all the different forms of ear disease ; for instance, it may depend upon the accumulation of wax, or it may be due to some other temporary disorder of the ear, which can easily be cured by proper local treatment, or it may occur in patients whose auditory apparatus is normal, from the action of drugs, from changes in the circulation, or as a part of some general morbid condition.

More commonly, however, some chronic ear mischief exists and the removal of the subjective noises may be a matter of great interest to the patient, even apart from his deafness. When patients are electrically tested it is found that sometimes the tinnitus is associated with greatly-increased irritability in the auditory nerve, which is shown by the ready production of an impression of sounds by small currents. As a rule, the kathodal closure produces an increase of sound and anodal closure reduces the sensation of sound which is felt, and this effect is very well marked in these patients. The effect of the anode in temporarily diminishing the noises is sometimes very apparent. The usual effect of the application of the anode to the ears is to diminish the noises, while that of the kathode is to increase them.

Various other electrical applications have been advised for tinnitus aurium. Brigade-Surgeon W. Price, writing in the *British Medical Journal* in 1900, describes a method which he has found efficacious in his own case. He writes : " The negative cord from a good coil is attached to a large copper electrode ; from the positive terminal two cords are brought, each attached to an ordinary hand electrode. Both feet are placed against the negative electrode ; each hand grasps one of the positive electrodes. The coil is now set working until the strength of current is as much as can be endured with comfort. The knuckles of one hand are now applied to the affected ear. The

amount of current passing through the ear can be regulated to a nicety as follows: Slightly open the hand against the ear; the current is at once proportionately decreased. Shut that hand while opening the other, and the current through the ear is at once increased. In my case this treatment is followed by almost instant relief, and the 'cure' is quite as permanent as when the case is left to Nature. When it threatens to return another application relieves."

The brush discharge of the static machine or the effluve of high frequency directed into the external auditory meatus has also been recommended.

307. **Eustachian Obstruction.**—A. E. Cumberbatch and W. E. Steavenson* have described a method of electrolyzing the Eustachian tube in cases of deafness associated with pharyngeal catarrh. Their instrument consists of a vulcanite Eustachian catheter and an electrical bougie (Fig. 182). The bougie is

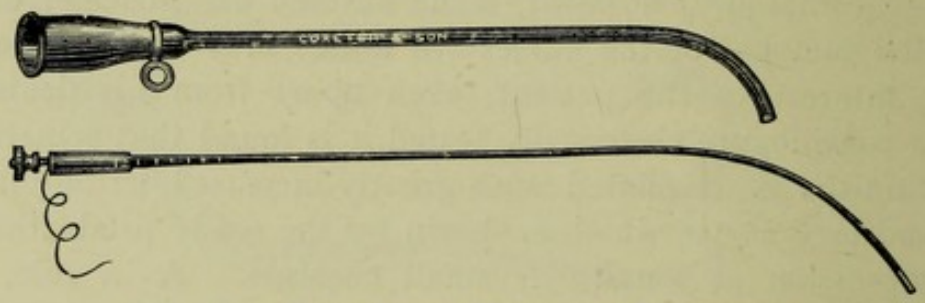

FIG. 182.—EUSTACHIAN CATHETER ELECTRODE.

made of a fine flexible copper cord about seven or eight inches long, insulated by vulcanite to within an eighth of an inch of its end. The catheter is first placed in position, and the bougie is then passed along it. A pad connected with the positive pole, and placed at the back of the patient's neck, completes the circuit. A galvanometer should be included in the circuit, and the current gradually increased up to four milliampères. A crackling noise will be heard by the patient. The electrolysis is kept up for three or four minutes, and usually before the expiration of that time it will be found that the bougie can be pushed on for a small distance. Improvement in hearing is certainly produced in some cases by this procedure.

308. **Cutaneous Affections.**—The treatment of various forms of skin disease by electrical applications has been much extended in recent years, particularly by the employment of X-rays and

* *Lancet*, November 24, 1888.

high-frequency currents. Other forms of electrical application are also used. I have seen prompt and permanent healing follow treatment of a varicose ulcer of long standing by the interrupted current. Patients who are taking a course of electric baths usually lose any acne of the skin of the back from which they may have been suffering at the commencement, and it is well known that chilblains respond favourably to electrical treatment. These facts all show that the nutrition of the skin can be markedly influenced by electrical applications.

The static breeze, the brush discharge of high frequency, and the Röntgen rays, all show marked effects upon the skin which can often be turned to good account in treatment.

Dr. Marquant* has reported a series of twenty-three cases of eczema and eczematous ulceration treated by the electrostatic brush discharge with very good results. The patients were negatively charged, and the affected part was submitted to the brush discharge from a positive point. The local pain and the congestion and discoloration round the ulcers quickly disappeared, and healthy cicatrization commenced rapidly.

E. Doumer also in 1894 reported a number of cases of eczema treated successfully by static discharges.

Denoyés enumerates the following skin affections as benefited by high-frequency discharges : Pruritus, psoriasis, eczema, alopecia areata, lupus vulgaris, and erythematosus, acne, and impetigo. In all the technique is similar, and consists in the use of the effluve given without sparking from a metallic brush electrode, or with the glass vacuum-tube electrodes (Fig. 144).

In some indolent conditions it may be useful to apply a few fine sparks to the surface by means of a point electrode.

It is also thought that general applications of high frequency by the condenser couch are a useful adjunct to the local treatment, and cases have been several times recorded where general treatment and local applications to one patch of lupus have been followed by a cure of patches of lupus remote from the one locally treated.

X-rays have been used with good therapeutic results in a number of cases of acne vulgaris, eczema (chronic), psoriasis, and verruca vulgaris, and also in certain parasitic affections of the skin, as favus, sycosis, tinea tonsurans.

X-rays are also extensively used for lupus vulgaris, and with

* *Archives d'Électricité Médicale*, 1894, pp. 329, 385.

less success in lupus erythematosus. In chronic ulceration of syphilitic origin and in " varicose " ulcers of the leg their effect is often remarkably good. It does not appear that the effect is due to any bactericidal action of the X-rays.

309. **The Removal of Superfluous Hair.**—If a fine needle connected to the negative pole of a battery of three or four cells be introduced into a hair follicle, electrolysis takes place round the needle when the circuit is closed, and the hair follicle is destroyed by the alkali produced; the hair can then be removed easily, and does not grow again.

The method of operating is as follows: The patient should recline in a good light. Having placed the indifferent electrode (anode) in contact with a convenient part of the patient's body, the kathode is attached to a fine platinum wire set in a handle, the current collector is turned on to take up three cells into circuit. The operator then introduces the needle as closely as possible to the root of the hair, holding it in the proper direction for it to enter the follicle. The needle passes down readily to the required distance (one-eighth or one-sixth of an inch), a current of about two milliampères passes, slight effervescence is seen at the orifice of the follicle, and at the end of five seconds or so the needle is withdrawn. As a rule, the hair can then be lifted out easily by a forceps; if it still remains firm, the needle may be introduced a second time until it is loosened, though this is best avoided. There is a certain amount of pain, but it is within the limit that can be borne without flinching, and an anæsthetic is not necessary. Cocaine cannot be usefully applied.

It is best to use for the needle a very fine platinum wire, blunt-pointed, because such a needle is less likely to penetrate

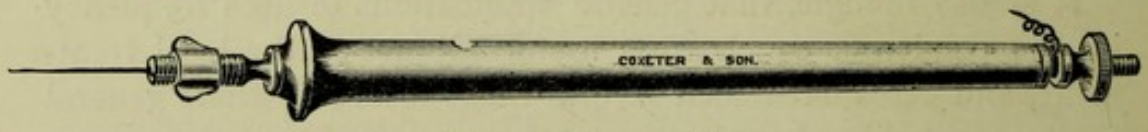

FIG. 183.—NEEDLE-HOLDER ELECTRODE.

too easily and so to pass away from the hair follicle. It should be sterilized before use by heating to redness, and is better than a steel needle. The latter will leave indelible black marks if by accident it be used when connected to the positive pole. The current must be closed before the needle is inserted into the follicle. A key in the handle is therefore unnecessary and troublesome.

A good deal of practice is required to perform this little operation skilfully, for it really amounts to a catheterization of the hair follicles. No force must be used in removing a hair; if force is used the hair will come out before the follicle is destroyed, leaving its root behind, and a new hair will grow up from it. It is possible with a good patient to remove thirty or forty hairs at a sitting. A tiny eschar with a small zone of redness is left round the follicle. Several hairs in close proximity should not be attacked at one time, for fear lest the injury to the skin should lead to a scar, but the hairs should be removed sporadically.

It is as well to caution patients that there will be a certain percentage of returning hairs, but that these can be dealt with a second time if any should so return.

It is very easy to overdo the treatment and leave scars. It is not wise to attempt the total removal of a fine downy growth of the upper lip of young women.

The permanent removal of superfluous hairs from the skin by exposure to the X-rays requires very careful management to cause the desired shedding of the hairs without producing injury of the skin itself. The risks of causing serious damage to the skin have deterred operators from developing this method of removing hairs for cosmetic purposes, although in cases such as sycosis and tinea, where the hair must be temporarily removed for the cure of disease, or in unsightly hairy moles, the removal of the hair by X-rays is frequently performed.

Its risks as a cosmetic process are due to the probability of injurious effects upon the texture or colour of the skin, such as pigmentation, reddening, or the formation of telangiectases, the appearance of which would suffice to defeat the desired object of improvement in the personal appearance.

It is comparatively easy to cause hairs to fall out as a result of X-ray applications, but it is difficult to do it in such a way as to prevent their return subsequently. The safest procedure is to cause a temporary falling out of hair, as in Sabouraud's treatment of ringworm (§ 312), and to repeat this after the lapse of one or two months. Several such repetitions produce a more or less complete and permanent disappearance of the hair.

The removal of eyelashes for trichiasis is satisfactorily accomplished by electrolysis, but it is difficult to carry out, owing to the sensitiveness of the part, and the fineness of many of the

most troublesome hairs. The results of the treatment of this complaint are very satisfactory. Usually at the commencement of the treatment the corneæ are hazy, in consequence of the continued irritation by the turned-in eyelashes, but if the removal of the eyelashes be persevered with until every one has been removed, the corneæ will recover their transparency, and the patient will continue free from any recurrence of trouble from the ingrowth of the eyelashes.

310. **Moles.**—The best treatment for small hairy moles is epilation. When the hairs have been removed, very little will be seen of the mole, for the prominence on which the hairs grow will disappear. A good deal of the pigmentation of the skin between the hairs will also disappear when they have been taken out; but if there be much pigmentation, the best treatment is by transfixing the mole in several directions, using the negative needle and five or six cells. Cocaine electrolytically introduced can be used to render the part insensitive. A small pad of lint wetted with a pure solution of cocaine hydrochloride (5 per cent.) should be laid over the part, and a platinum or carbon electrode placed on this, and connected to the positive pole, will produce a superficial anæsthesia in five or six minutes.

311. **Alopecia Areata.**—High-frequency applications with the vacuum electrode are useful in a general way to stimulate the growth of hair, and have been found to do good in cases of ordinary alopecia areata.

When there is reason to suspect the presence of some parasitic infection—as, for instance, when the disease attacks more than one member of a family—an electrolysis of the affected patches with a copper salt, using a copper anode, is valuable. This application has a decided parasiticide effect, and each patch, together with a surrounding zone, should be treated once in this way. At a later period the stimulating effect of high-frequency discharges may be employed to promote the rate of growth of the new hair.

A solution of copper sulphate at 2 per cent., or of zinc sulphate at 4 per cent., on several layers of lint, applied for 15 minutes with a current of 2 or 3 milliampères per square centimetre, is a suitable application.

The condenser spark lamp or arc lamp with water-cooled iron electrodes has been used with advantage in the treatment of

alopecia areata. Kromayer,* dealing with this treatment, points out that when areas of skin are exposed to the light for a short time—for example, three minutes—a reddening of the skin appears, and may last for days or even weeks, and he attributes the success of the applications to the hyperæmia produced by them. During fifteen months Kromayer has had 6 cases of alopecia under his care, which had previously been treated without effect by various drug applications, and finally were subjected to treatment by the iron electrode lamp. All these cases were extensive and severe, and two were alopecia totalis. In one of the two the light treatment was carried out from February 25 to May 12, in fifteen sittings of from half an hour to three-quarters of an hour duration. Each portion of the scalp was exposed to the light for four minutes. The reaction was well marked. The principle followed was to produce the reaction, and keep it up for fourteen days ; then to pause until the result could be determined, and eventually to repeat the whole process. When seen in June, the patient was found to have hair over the whole scalp, and in some parts the growth was quite luxuriant. The other five were treated in a similar manner, and one was completely cured after one treatment cycle, one after three cycles, one after six.

312. **Tinea Tonsurans.**—The treatment of ringworm of the scalp by X-rays has been made a practical success by the labours of Sabouraud, who has elaborated a system of measurement by means of which the necessary exposures may be accurately given in a single sitting. Good descriptions of Sabouraud's mode of procedure have several times been given in the English medical journals, but perhaps the best will be found in the address by Sabouraud himself delivered before the Dermatological Society, and printed in the journal of the society.† In the treatment of ringworm the point of chief importance is the dosage of the X-ray applications, and this is effected by means of the pastilles of platino cyanide of barium, described in § 153. In the paper referred to Sabouraud has given the following details :

The patient is examined, and if the patches of ringworm are few in number, the whole affected area may be included in a

* *Deutsche Medizinische Wochenschrift*, July 28, 1904.

† "The Radiotherapeutics of Ringworm at the Municipal Laboratory of the City of Paris at the Hospital of St. Louis," R. Sabouraud. *British Journal of Dermatology*, June, 1906, with plates.

single application of X-rays ; but if the patches are numerous, it may be necessary to depilate the entire scalp, and in this case it will be necessary to make a series of exposures. For this purpose localizers composed of metallic cylinders of different diameters are used, care being taken that they are not so large that the head may form inside them too great a convexity. A localizer is applied by hand to the scalp, and a tracing of the areas to be irradiated is made with a brush dipped in ink, so as to insure that no single diseased point upon the head shall escape the action of the X-rays.* When the first area has been exposed it is covered with a disc of lead, held in place by an elastic band, and the second area is then proceeded with, and so on for the others. Sabouraud states that in this way it is possible to make the ten or twelve exposures necessary to depilate the entire scalp without any time-interval between them, and that the patient runs not even the risk of a headache. Towards the conclusion of the operations necessary for the depilation of the whole scalp the head of the patient will be covered over with sheets of lead, which leave free only those spaces, of all shapes, which have not been subjected to the rays. At the conclusion of the exposures the scalp exhibits no change in appearance, and will remain thus for about fifteen days, but after that time the hair will fall under the influence of the smallest traction, all the hairs having their root-end atrophic and pointed.

On the eighteenth day the head should be washed with soap, rubbing and pulling out with the fingers all the weak hair, in order to avoid the dissemination of germs, for the fungus is not killed by the X-rays.

When the head has been bare for ten to fifteen days the roots of trichophytic hairs may still be seen imbedded in the skin. They are the last to fall, and must not be allowed to remain, for they might reinfect the new hair. Daily washings with soap will remove them, and by the thirty-fifth day the head thus treated should be entirely bald and free from all diseased hairs. From the first day the entire head should be anointed daily with tincture of iodine diluted with nine parts of rectified spirit.

This application destroys any free spores, and when a scalp need not be entirely depilated it prevents the infection of the healthy parts.

The head thus treated remains bald for two months. It then

* See figure *op. cit.*

becomes covered with lanugo and adult hairs, sometimes at first in a very irregular way. At other times, again, the healthy hair comes back in islands, marking exactly the place of the ringworm patches. In any case, the new growth ought to be, in normal circumstances, complete within four months.

The pastilles used for measuring the exposure should be covered by black paper while under the influence of X-rays, for daylight retards the changes produced by the rays. They are compared with a standard tint called "Tint B," which is supplied with the books of pastilles. This tint is such that when the pastille placed at $7\frac{1}{2}$ centimetres from the antikathode becomes of the same colour, the skin at 15 centimetres will have received the exact quantity of X-rays necessary to insure the complete depilation of the region without producing dermatitis, and without compromising the ultimate regrowth of hair. It is, moreover, the exact maximum quantity that the human skin can receive in a single sitting without injury.

When the colour B of the radiometer has been exceeded, the regrowth is likely to be retarded in places for a month or six weeks, and it must be understood that hair which has not come back within six months will never grow again. After exposures which have been too strong, but yet not excessively so, a permanent loss of hair may result, although no dermatitis may have been produced. The X-ray treatment of ringworm is, therefore, a delicate method.

Sabouraud further adds that there are many degrees between perfect growth, on the one hand, and the complete destruction of the hair bulbs on the other. When the tint B has been exceeded, one may see a growth which is woolly, crinkled, and "Ethiopian." Or, again, upon a patch which has been too much treated the hair may come back thinly.

Insufficient applications also conduce to different bad results. Diseased hairs may remain, and the whole process may require doing afresh. Such a second exposure should not be made on the same place within the month, but after the lapse of this time the exposure may be made anew without running any more risk of lack of regrowth than at the first sitting.

Dr. Sabouraud considers that the proper position of the pastille is at 7·5 centimetres from the target, while the region irradiated should be at exactly double that distance—viz., 15 centimetres. The pastille should be distant at least 2·5 centimetres

from the glass wall of the tube, in order to avoid a misleading effect from the warmth of the glass, which tends to vitiate the indications by accelerating the colour change in the pastille. A small X-ray tube is therefore essential.

He considers that idiosyncrasy may be neglected in X-ray work, and states that two of his nurses have made 7,000 exposures since May, 1904, without coming across one instance of idiosyncrasy, and without a single case of dermatitis, by relying upon the indications of the pastilles of platino-cyanide of barium. Messrs. Watson and Son have recently brought out a form of pastille holder which permits of ready adjustment of the position of the pastille, and, while protecting it from daylight, allows of easy inspection during the progress of the exposure.

Sabouraud encloses his X-ray tubes in large cylindrical covers of sheet-iron lined with ebonite, and having an opening on the side corresponding with the point of emergence of X-rays. To this opening the "localizers" are adapted by a bayonet catch. These localizers are metallic cylinders, all of the same length, but with different diameters. Their variation in size is necessitated by the variable dimensions of the patches on the scalp which it is desired to expose to X-rays. Their impermeable walls protect from oblique, diffuse, or aberrant rays the operator and the parts of the scalp in juxtaposition to that which is being treated.

They are so arranged that the skin, when in contact with the external orifice of each, is exactly fifteen centimetres from the antikathode. The contact of the margin of the localizer with the scalp insures immobility during the exposure.

Ionic medication with salts of copper or zinc may be used for ringworm and other parasitic affections of the skin or scalp. The writer has obtained very striking results with both of these metals in cases of ringworm, the bald patch becoming rapidly covered with a growth of healthy hair after one or two electrolytic applications. Care must be taken to remove grease from the affected area before commencing the electrolysis, as, if this is not done, there is considerable difficulty in obtaining a uniform penetration of the drug. A preliminary soaking for half an hour of the area to be electrolyzed with the solution upon several thicknesses of lint is useful.

313. **Favus.**—The X-ray treatment recommended for ringworm may also be used in favus. Sabouraud states that favus with

scutula is not cured with certainty by a single exposure to X-rays, though one application, if well made, may cure four-fifths of the disease. His advice is to practise depilation by forceps over any points upon the exposed surface at which new scutula have made their appearance. Less severe cases of favus without scutula may ordinarily be cured in one sitting.

314. **Sycosis.**—This condition may be treated by the method of causing depilation by X-rays, as in ringworm of the scalp. E. S. Worrall* has reported three successful cases in which five or six applications of the rays for ten minutes sufficed to cause depilation with cure of the disease. In one of his cases the patient's chin and upper lip were covered by sycosis. This was rayed five times for periods of six to ten minutes, when the hair began to come out freely and the treatment stopped. A fortnight later the case was quite cured.

In another case, aged thirty-eight, there was coccogenic sycosis of seven months' duration. It commenced on the upper lip, and the affected area included the upper lip, the chin, the side of face, and part of scalp. The patient was rayed seven times, the last exposure being on April 25. By May 13 there was complete epilation, and the disease was cured without any further application.

Copper electrolysis can also be employed in sycosis. W. J. Morton† in 1898 reported the successful treatment by electrolysis of a case of sycosis by using a copper needle to puncture the affected spots. It is probable that equally good results would be obtained by means of copper electrolysis without puncture.

315. **Furuncle and Carbuncle.**—The local treatment by electricity is advocated by Marcus.‡ Previous to the appearance of suppuration, he opens the follicles of the affected area, and introduces into them an epilation needle connected with the negative pole. Through this a current of one to two milliampères is passed at first, which is afterwards increased to ten. By slightly moving the needle around, the opening of the follicle is considerably enlarged, and a quantity of frothy serum is soon poured out, containing portions of tissue and numerous cocci. Then the needle is removed, the spot is carefully cleansed ; the needle

* *Medical Electrology and Radiology*, July, 1906.

† "Cataphoresis," by W. J. Morton, New York, 1898.

‡ *Münchener Medizinische Wochenschrift*, 1905, No. 21.

is again introduced, and one or two milliampères are allowed to pass. The positive pole is now to be connected with the needle, and the current again raised to ten milliampères. This causes the liberation of acid, which is always more energetic in its nascent condition. In two or three minutes the treatment is suspended and the surface again washed with water. Each affected follicle is treated in the same manner. If suppuration has already commenced, a larger needle is introduced into the follicles and moved around, until the entire greenish-yellow pus plug is broken up and disappears in foam. Then the positive pole is introduced, and again followed by the negative pole. A wet dressing is applied. The author states this treatment is not applicable to large carbuncles.

It is probable that the method described by Marcus would be improved by the employment of needles of zinc or of copper connected to the positive pole.

R. Coyle* has reported a good effect upon carbuncle by X-ray treatment.

316. **Acne.**—Cases of acne improved by X-rays have been reported by several observers. A course of mild exposures at intervals of a week has a decided influence upon the development of the pustules, but it is not yet established that anything more than temporary benefit can be obtained.

J. Belot† gives a summary of the literature of the X-ray treatment of acne, quoting numerous writers, and he considers that the X-rays should be reserved for the more serious cases, inasmuch as very good results may be obtained by the simpler procedures of high-frequency brush discharges.

317. **Nævus.**—When, by reason of its situation or its size, excision of a nævus cannot be satisfactorily performed, electrolysis is a convenient mode of treatment, and for certain cases it is superior to all other methods; but, to secure good results, a certain amount of practice is necessary, and several repetitions of the operation may be required if the nævus is an extensive one. The chief art in treating a nævus lies in the careful regulation of the current used and in knowing when to stop. It is easy to electrolyze a nævus in such a way as to destroy it and cause it to slough away completely, but this leaves a large scar and is

* *Medical Electrology and Radiology*, June, 1906.

† "Radiotherapy." Translated by W. Dean Butcher (Rebman: London, 1905).

not the best way of attaining one's object. The object to be aimed at in the electrolysis of nævi is to carry the destructive action just so far as to coagulate the blood and break up the bloodvessels without producing a general necrosis and sloughing of the whole. When the nævus is entirely subcutaneous, it is most important to save the skin, for then the nævus is removed without any scar, except at the minute points where the needles were introduced. When the nævoid tissue is quite superficial and very florid, and involves the actual thickness of the skin, it is difficult or impossible to destroy it without some scarring. In a large number of cases the galvano-cautery, if dexterously used, gives results which are as good as those of electrolysis, and gives them more rapidly ; but a fine point is required, and it must not remain long in one place, and it must be made to penetrate the full thickness of the nævus. A superficial scarring is of no use.

Those nævi which can be easily excised should be treated by that method, and electrolysis or cautery should be reserved for those which are difficult to do in that way. If the nævus is very small—that is to say, under a fifth of an inch in diameter —it may be completely destroyed in one sitting, and the resulting scar will not be of any great moment ; and here I would urge very seriously the importance of dealing with nævus at the first possible opportunity after birth. Nævi which are quite small at birth are often allowed to grow large before any interference is thought necessary, with the result of disfigurement which might have been prevented. Unless nævi are large, the first application should aim at complete destruction, or, at least, the major part of the nævus should be got rid of at the first treatment.

Nævi may spontaneously disappear, but this is a rare occurrence, and the usual tendency of a nævus in the young baby is to grow rapidly. Indeed, after treatment a nævus will often commence to grow afresh, although at the time of operating it seemed to have been completely destroyed. Such reappearance may take place in a nævus which has been perfectly healed for two months. The margin of a nævus is the part most prone to fresh growth, and this part must be attacked most thoroughly.

Nævus is commoner in females than in males, and it is found on the head and neck more often than upon the trunk or limbs. Out of 173 consecutive cases in the Electrical Department of St. Bartholomew's, 121 were in female and 52 in male children ;

in about three-fifths of these the nævus was situated on some part of the head or neck. Nævus may occur on the ocular conjunctiva. At the anterior fontanelle nævi are common, and can safely be treated by electrolysis; the needles, of course, must not be pushed into the brain.

The usual plan of treatment is as follows: Needles attached to one or both poles of a battery are introduced into the nævus, a galvanometer being included in the circuit; the current is then very gradually raised from zero up to 20, 30, or 40 milliampères.

If both poles are used, care must be taken that needles of opposite poles do not touch one another, for if they remain in contact the current simply runs to waste through the metallic circuit so produced, and the nævus tissue is unaffected; if they come into momentary contacts, the patient receives a shock each time they touch and separate. Soon after the commencement of the operation the tissues round the needles begin to change colour; round the positive needles there is hardening and pallor, and round the negative needles frothing is produced with the evolution of hydrogen gas. The positive needles become firmly adherent to the tissues in which they are embedded, and force is required to withdraw them; on this account bleeding is more likely to occur with the positive than with the negative needles. The negative needles become loose and are apt to slip out, but they must not be allowed to do so, for the current must not be suddenly interrupted. If the tissues round the needles become livid or blackened sloughing of the part will follow. This change shows itself first at the negative pole. The position of the needles must be altered before this, by taking them out and reinserting them one at a time in other parts of the nævus, until the whole of it has been treated.

The needles are to be withdrawn after the current has been lowered, and must not be plucked out while the current is still running strongly. The positive needles may be adherent, and should be twisted out gently. A little bleeding may follow from one or two of the punctures, but it is rarely of any importance. The after-treatment is simple. Collodion containing iodoform (one drachm to the ounce) is to be painted over the nævus. This can be left for four or five days, but should then be removed, and the place treated with boracic ointment, or if any suppuration or local sloughing should develop, some zinc lotion

or lint will be a suitable dressing. Many nævi heal quickly, and need no second application. It is impossible to avoid some destruction of the skin and some scarring when the nævus is cutaneous, but the scars produced are much smaller than might be expected, and when seen a year or two afterwards they show remarkably little.

Sometimes only one needle or set of needles, usually the negative, is introduced into the nævus, the circuit being completed through the patient's body by using a large pad for an indifferent electrode. In this case the resistance is higher, and a larger number of cells is required, and there is a greater risk of shock or faintness, especially with nævi on the head or face. This unipolar method is most suitable in cases where great nicety is needed, as, for example, in small nævi about the eyelids or nose.

The rate of destruction depends upon the density of current in the part. If needles of both poles are introduced irregularly, it is very likely that the current may be strong round the points where they are nearest together, and be weak in the more remote parts. The diagrams (Fig. 184) represent

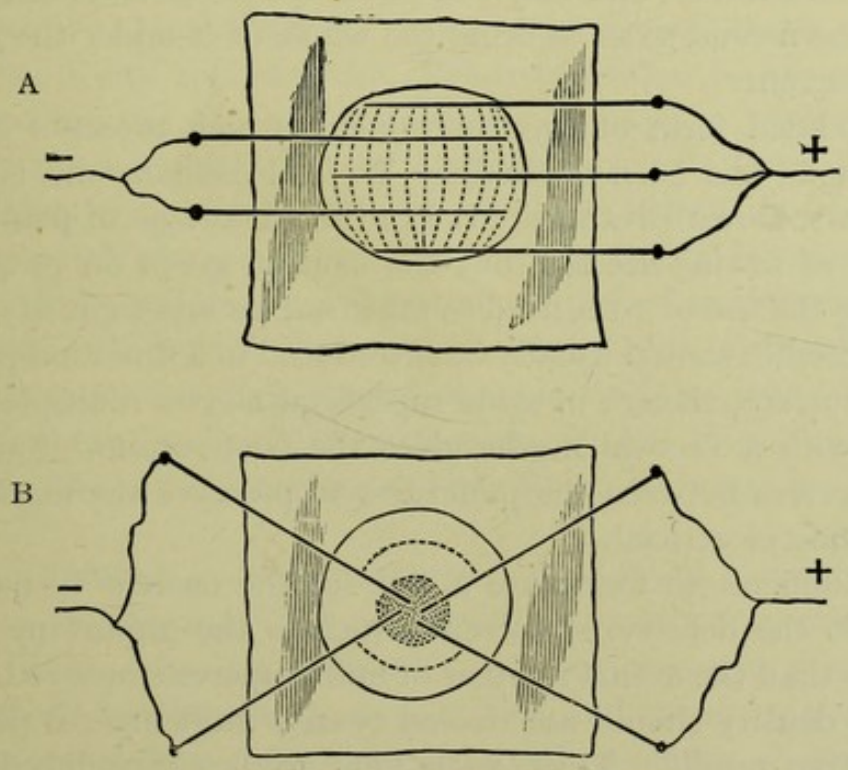

FIG. 184.—ELECTROLYSIS OF NÆVUS.
(A) Proper and (B) improper position of needles.

the conditions under two different arrangements of needles, first with the needles placed evenly, and the density of current uni-

form ; and, secondly, with the needles close together at the points, and the current concentrated unequally.

In order to simplify the introduction of the needles in a proper manner, the writer* has devised an instrument (Fig. 185) consisting of a handle to carry the needles. Two, three, four, or five can be screwed into it, and they are so arranged as to be

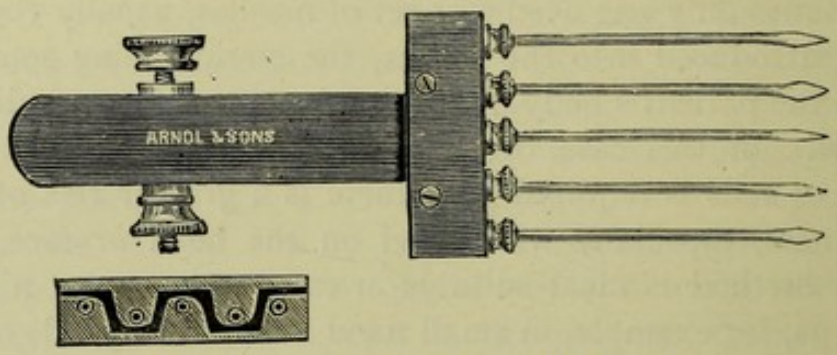

FIG. 185.—BIPOLAR FORK ELECTRODE.

alternately positive and negative (see the smaller of the two figures). By this means the needles are kept at equal distances from one another throughout the operation, and they cannot touch accidentally, and they can be moved about simultaneously inside the nævus, so as to bring the whole of it under the action of the current.

A modified form of this instrument, which presents certain advantages, has been devised by W. T. Freeman, and is made by Messrs. Down Brothers. It has the advantage of permitting the use of sewing-needles, but the caution given on p. 492 respecting the use of steel needles must not be lost sight of.

The needles should usually be introduced in a direction parallel to the surface, though in some superficial nævi a multiple puncturing with a vertical needle gives the best results. Sufficient skin survives between the punctures to preserve the mark from being truly cicatricial.

It is difficult to formulate a rule for the current to be used, but it is the density of current which is the important point, more so than the actual number of milliampères employed. The current density should not exceed twenty milliampères per inch of positive needle. Thus, with four needles introduced for a distance of half an inch, two being positive, a current of twenty milliampères would be amply sufficient, and with two needles

* Lewis Jones, "An Improved Instrument for the Electrolysis of Nævi," *British Medical Journal*, February 20, 1892.

introduced for twice that distance the same current would yield the same effects.

318. **Port-wine Mark.**—This form of nævus can be attacked by a tattooing process, using a fine needle, and inserting it vertically into the skin; the current used must be less than five milliampères, and the application at each point quite brief. There is no need to use several needles at once. The operation should produce minute points of destruction without confluence of the resulting minute scars. The negative pole is best. If a port-wine mark be closely scrutinized, the position of many of the capillaries can be seen, and these are the points into which the needle must be especially directed. The area affected must be treated in a sporadic manner at successive sittings as advised for the removal of superfluous hair. The result is a distinct improvement in the aspect of the surface; the treatment must be carried out slowly. It is so long a process that it is not often undertaken.

319. **Eczema.**—X-rays are of striking value in many forms of eczema. The exudation tends to disappear, the itching quickly goes, and the crusts and scales are shed, and do not form anew. Many writers have experienced these striking results of X-ray applications. Belot states that he has obtained a complete cure of the local lesions in cases of eczema, and advises the administration of a single moderate dose, followed by a repetition after the lapse of eight or ten days. For a chronic patch of eczema, with thickening and infiltration of the skin, a single full dose equal to that employed in ringworm may be given. He points out, very properly, that, although radiotherapy cannot replace careful regimen and hygiene, it has a special value by being efficacious in certain forms of chronic eczema which are particularly rebellious to other local treatment.

320. **Psoriasis.**—This condition also reacts favourably to X-rays. H. Marques* has reported the case of a man twenty-five years of age who had suffered from psoriasis of a pronounced type of the hands, elbows, back, chest, and knees for four years, despite treatment by numerous medicaments. X-rays were applied at first to the hands. A soft tube was used, with the antikathode at a distance of six and a half inches, the exposure being for five minutes on the dorsum and five minutes on the

* *Archives d'Électricité Médicale*, 1905, p. 163.

palms of the hands. Treatment was given every two or three days. After two weeks the sound skin was decidedly erythematous, but the scales were falling off, and the intolerable itching had entirely disappeared. This was all the treatment required for the hands.

Other affected regions were then subjected to similar treatment, and with the same success. Five months after the end of the course of treatment, which had taken only a month and a half in all, there had been no recurrence. The static breeze and high-tension effluvia had previously been tried in this case without any effect.

In a case of my own a chronic psoriasis of seven years' standing was almost completely relieved by a course of X-ray applications. The patient had very numerous spots and patches of psoriasis upon the trunk, limbs, and scalp. She was treated by exposures given every four or five days for a month, and when seen again a month later there was an almost complete absence of all sign of the disease, except at the margins of the hairy scalp. This region had not been irradiated, owing to apprehensions of a bad effect upon the hair. When seen a year later, the patient still had occasional appearances of spots of psoriasis, but the severe condition which existed before the X-ray treatment had not returned.

321. **Pruritus.**—In pruritus of the anal and pudendal regions X-rays have been very successful, and a course of ten or twelve applications at intervals of one or two weeks are sufficient to cure most cases. The patients frequently report that the itching is aggravated for a few hours immediately after the exposure to the rays, but when this has passed off the condition becomes comfortable, until after a few repetitions of the rays the pruritus disappears altogther.

The effluve of high frequency, or applications with a glass vacuum electrode, also act favourably in many of these cases of pruritus.

322. **Ichthyosis.**—Leduc has reported the case of a boy of twelve, whose body since infancy had been covered with brownish-black scales, which desquamated and were renewed incessantly. Every form of treatment, both for the condition of the skin and his general health (which was precarious), proved useless. On April 4, 1905, an exposure of X-rays was made with a low tube, the antikathode being 40 centimetres from the part treated.

The head, trunk, and limbs were successively exposed for a total period of twelve minutes. A fortnight later the boy appeared better, desquamation had been abundant, but the scales had not recurred, and islets of white skin could be seen. A second exposure, similar to the first, was given on April 19, when continued improvement was observed. His general health was better, and he was growing and putting on flesh. A third exposure was given on May 8. On June 8 almost all the skin appeared normal ; there were only a few small scaly patches on the ears, arms, and legs. A fourth exposure was then given, and in July the whole of his skin was normal, and his general condition very satisfactory.*

323. **Keloid.**—Moseley has reported the case of a man thirty-five years of age, who in 1900 had a nævus of the right cheek removed. A keloid appeared, and on February 15, 1903, the patient presented a keloidal mass about 4 inches long running downward and forward on the cheek. In all twelve treatments were given, extending from February 15 to May 19, exposures to the X-ray being of ten minutes' duration and employed three times a week. On May 15 an erythema began to appear, the skin became inflamed, and the keloid commenced to flatten.

O. S. Barnum† advises the use of a high tube, and exposures made at a distance of 15 to 20 inches for fifteen to twenty-five minutes on alternate days, until eight or ten applications have been given, and adds that treatment must be stopped at the first sign of reaction in the neighbouring healthy skin. He recounts three cured cases of extensive keloid.

324. **Warts.**—The groups of warts which form upon the hands may be treated by electrolysis with magnesium ions. Two cases treated in this way under my own care were cured by one or two applications. In the first the warts were very numerous on the dorsum of the hand and the lower part of the forearm.

A circular pad of lint was applied to the back of the hand. It was moistened with a 5 per cent. solution of magnesium sulphate, and the current introduced by means of a carbon anode. A fortnight later the position of the pad could be distinctly traced upon the back of the hand, for the warts had entirely disappeared within that area, though they remained unaffected

* *Archives d'Électricité Médicale*, September 10, 1905.

† *Archives of Physiological Therapeutics*, 1906, i., p. 170.

outside of it. In the second case, the warts on the back of a child's hand were removed by similar applications repeated twice. The control areas above and below the site of the pad were unaltered, and still presented many warts, while all those included in the electrolysis faded away completely within the following month.

325. **Lupus Vulgaris.**—Much has been written of late years on the subject of the treatment of this disease by physical methods. The famous work of Finsen in the treatment of lupus by concentrated light has excited widespread interest, and has stimulated others to attempt the cure of the disease by other methods, among which the use of X-rays is perhaps the most important. X-ray treatment has the advantage that it can be applied over a much larger area at a time than is possible with Finsen light, and this tends to reduce the time consumed during the treatment—an important consideration in many cases.

Dr. Malcolm Morris and Dr. E. Dore, in a valuable paper on the treatment of lupus, have compared the effects of X-rays with those of the Finsen lamp in this disease.* The following is extracted from their communication :

" We have treated the majority of our cases of lupus vulgaris with the Finsen light, and the X-rays have mainly been employed as a preliminary in cases in which there was extensive ulceration or considerable œdematous thickening. The effect of the rays in bringing about rapid healing of ulcers has, in our experience, been so marked that we look upon ulceration as a definite indication for their use. Even one application often causes a notable diminution in the discharge from an ulcerating surface. In cases of severe deep ulceration relatively better results have been obtained than in slight superficial sores. This may be accounted for by the fact that in the deep ulcers little of the lupus growth is left and the new tissue is more healthy. When the ulceration is superficial, healing may occur over a mass of deep-seated lupus, and breaking down is more likely to occur. In a case in which there was severe ulceration of the mucous membranes of the lips and corners of the mouth some improvement followed the continued application of the Finsen light, but permanent healing resulted from a few exposures to the X-rays. In another case a small superficial ulcer of the

* *British Medical Journal*, June 6, 1903.

skin of the neck proved refractory to the light treatment, but the application of the X-rays produced rapid healing. In this instance, however, the healing was not permanent, and the ulcer had eventually to be excised.

" Rapid absorption of œdema under the influence of the X-rays has been observed in several of our cases. In one, in which there was marked œdema and protrusion of the upper lip with ulceration of its under surface and of the gums, the lip regained its normal shape and consistence, and the ulceration healed. This case was treated over a year ago, and no recurrence has taken place. In the case with ulceration of the angles of the mouth referred to above, the upper lip was also tense and protruding, owing to œdema, and the result of treatment with X-rays was equally satisfactory. Improvement is also taking place in two cases of extensive œdema of both sides of the face, in one of which there is also œdema of the lobes of the ears.

" When the disease is extensive the X-rays may be used as a preliminary to the light treatment. The advantage of this plan is that a large area may be treated at a time. In dealing with extensive surfaces, care must be taken not to cause severe dermatitis. We think it doubtful, however, whether permanent results can be obtained without the production of some degree of inflammation.

" When mucous membranes (lips, gums, nostrils, etc.) are the seat of lupus, the X-rays are, in our experience, more effectual than the Finsen light. When the inside of the nostrils is involved there is no choice, as the region is inaccessible to the light rays ; in all such cases, therefore, we have used the X-rays. The immediate results have been very encouraging, obstruction being quickly relieved, discharge ceasing, and ulcers healing after a few applications. It is only after a long course of treatment, however, that results of any degree of permanency can be obtained, and the tendency to relapse is very marked. We have treated only one case in which the palate was affected ; it was extensively scarred from frequent scraping operations, and the X-rays produced no beneficial effect.

" Another point on which we wish to lay stress is the palliative use of X-rays. Patients who, either owing to advanced age, ill-health, exigencies of occupation, residence at a distance, or other causes, are unable or unwilling to give up much time to

treatment may get considerable relief from a short course of X-rays. More than once we have succeeded by this means in checking the spread of the disease.

"Although the immediate effects of X-ray treatment, especially in cases in which there is extensive ulceration, are so good, our experience so far has been that the initial rapidity of improvement is, unfortunately, not maintained. Secondary conditions (ulceration, discharge, and œdema) are relieved almost at once; but in respect of eradication of the disease, progress is disappointingly slow, and failure is not infrequent. Opinions differ as to the possibility of entirely destroying the granulomatous tissue. Many cases have been reported in which nodules have remained after long-continued treatment. In non-ulcerative lupus the results seem to be less satisfactory as regards complete destruction of the foci of disease."

In the case of lupus high frequency applications may have a beneficial action. Chisholm Williams, Hall Edwards, and others, have written on this particular subject. In the Subsection of Electro-therapeutics at the Swansea Meeting of the British Medical Association,* the former read a paper from which the following extract is taken: "That the treatment of lupus by electrical currents of high frequency and high potential is a most excellent method will only be doubted by those whose experience of this form of electricity is of a limited character. As early as 1897 Dr. Brocq reported 62 cases, 16 of which were failures or abandoned the treatment, whilst the rest were cured. Lately Dr. Bordier has reported a series of 73 cases, with a like percentage of cures.

"The treatment may be applied in three ways: First, by the ordinary brush effluve; this, containing a vast quantity of ultra-violet rays, is, or should be, absolutely painless. Secondly, by means of a highly-exhausted vacuum electrode attached to the top of the resonator. When this is in actual contact with the skin it is warm, but not painful, and may be regulated by withdrawing it from the skin as desired. These electrodes should, with the fluorescent screen, give evidence of the presence of X-rays. Thirdly, by means of general electrization, preferably by auto-condensation. A combination of this with one of the former methods will prove of the utmost benefit."

High frequency currents applied with a small glass vacuum

* *British Medical Journal*, October 24, 1903, p. 1061.

electrode are a very convenient way of treating lupus in the nostril or in any other region difficult of access.

326. **Lupus Erythematosus.**—This condition is difficult to treat successfully by X-rays. Although some cases respond satisfactorily, there are others which remain unchanged or may even seem to grow worse under the treatment. It is also refractory to Finsen light treatment, and to high frequency applications. Temporary amelioration, however, is not uncommon with all these methods.

327. **Mycosis Fungoides.**—This uncommon disease has proved to be amenable to X-ray treatment, and many successful cases have been published. G. Stopford Taylor has reported the following case :*

"The patient, a man aged forty-seven years, first noticed a reddish painless lump of the size of a walnut over the middle of the spine in January, 1903. He did not apply any remedies, and after two or three months the lump disappeared. Before its disappearance five small similar tumours appeared over his left ribs. They never attained a larger size than that of a bean, and went away spontaneously about the same time as the large lump. For about twelve months he enjoyed good health, and saw no more tumours. At the end of that time there appeared scattered over his back a number of painless, reddish lumps of various size, which were freely movable. So far as the patient observed, his general health did not seem to be affected by them. The tumours grew slowly but steadily. In December, 1905, there were scattered over his back a number of tumours of varying size ; three of these were large, the largest being of about the size of a duck's egg. Large areas of the adjacent skin showed the pre-mycotic condition, which in this case was of the erythematous type, one large disc being very distinct. One of the smaller nodules was removed for the purposes of histological examination, which was made by Dr. F. P. Wilson. On cutting into the tumour, it appeared to the naked eye as a round mass, much denser and firmer than the surrounding tissue, and sharply marked off from it. Microscopical examination showed a mass of densely-packed cells in the corium. The cells consisted of connective-tissue cells of various shapes, numerous small round cells, and a few plasma cells. No mast cells were found. In some parts the cells were less deeply stained and were crenated in

* *Lancet*, March 24, 1906.

appearance ; granular débris was scattered between them. In some parts of the specimen, especially round the periphery, the cells were arranged in columns. Outside the limits of the main mass foci of cells were scattered through the corium. The epidermis was thinned, and its interpapillary processes flattened out ; there was intercellular œdema.

"Treatment by the X-rays was given, with exposures of ten minutes' duration, twice a week at a distance of nine inches from the antikathode, 0·5 Holzknecht's units being administered at each sitting, with rays of penetration 7 on Benoist's scale. In all, fifteen exposures were given. The facility with which the tumours yielded to the treatment was remarkable, since improvement was noticed after the third sitting, and they were completely level with the skin before the hair fell from the adjacent parts of the back."

E. Worrall has reported a similar case.*

* *Medical Electrology and Radiology*, July, 1906, with illustration.

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DESCRIPTION OF PLATES

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DESCRIPTION OF PLATES.

Plates I.—VI.

The Motor Points.

PLATE

I. The Head and Neck.
II. The Upper Limb (*back*).
III. The Upper Limb (*front*).
IV. The Thigh (*front*).
V. The Thigh and Leg (*back*).
VI. The Leg and Foot (*outer side*).

Plates VII.—XI.

The Cutaneous Nerves.

VII. The Head and Neck.
VIII. The Upper Limb (*back*).
IX. The Upper Limb (*front*).
X. The Lower Limb (*front*).
XI. The Lower Limb (*back*).

PLATE I.

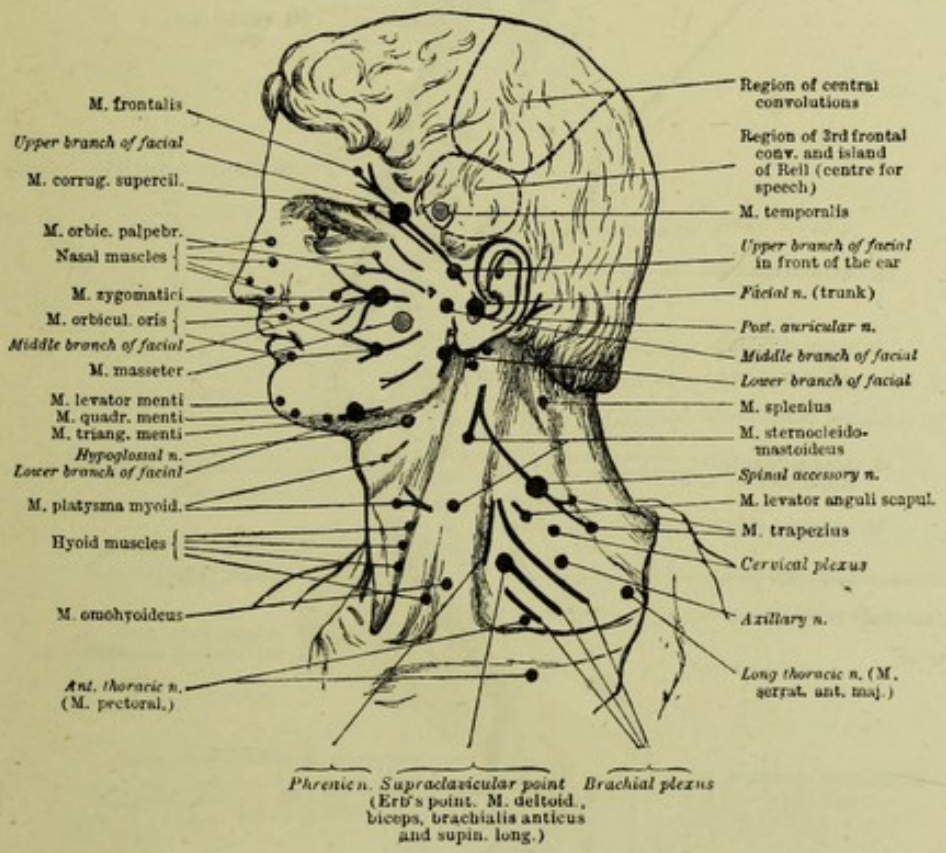

M. frontalis
Upper branch of facial
M. corrug. supercil.
M. orbic. palpebr.
Nasal muscles
M. zygomatici
M. orbicul. oris
Middle branch of facial
M. masseter
M. levator menti
M. quadr. menti
M. triang. menti
Hypoglossal n.
Lower branch of facial
M. platysma myoid.
Hyoid muscles
M. omohyoideus
Ant. thoracic n. (M. pectoral.)
Region of central convolutions
Region of 3rd frontal conv. and island of Reil (centre for speech)
M. temporalis
Upper branch of facial in front of the ear
Facial n. (trunk)
Post. auricular n.
Middle branch of facial
Lower branch of facial
M. splenius
M. sternocleido-mastoideus
Spinal accessory n.
M. levator anguli scapul.
M. trapezius
Cervical plexus
Axillary n.
Long thoracic n. (M. serrat. ant. maj.)
Phrenic n.
Supraclavicular point (Erb's point. M. deltoid., biceps, brachialis anticus and supin. long.)
Brachial plexus

PLATE II.

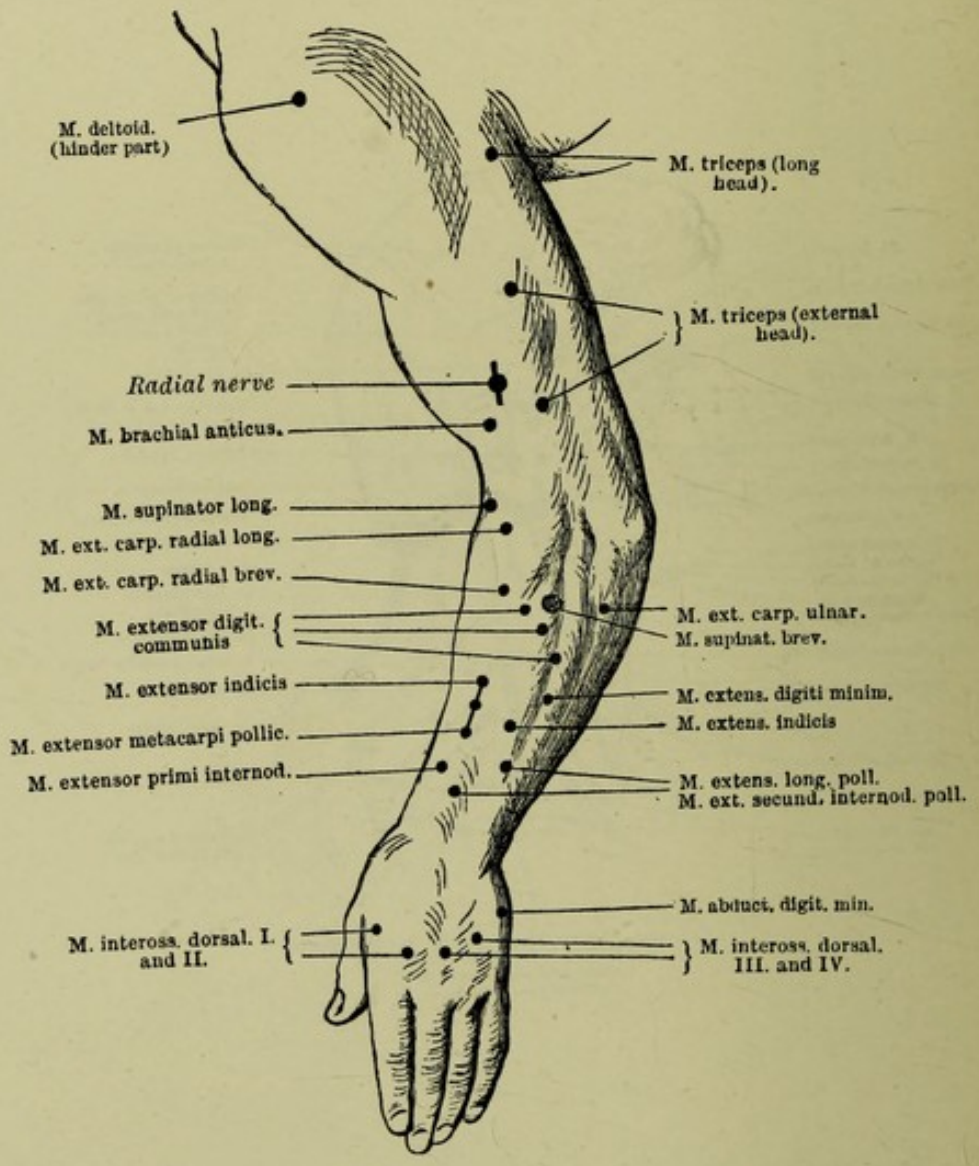

M. deltoid. (hinder part)
M. triceps (long head).
M. triceps (external head).
Radial nerve
M. brachial anticus.
M. supinator long.
M. ext. carp. radial long.
M. ext. carp. radial brev.
M. extensor digit. communis
M. ext. carp. ulnar.
M. supinat. brev.
M. extensor indicis
M. extens. digiti minim.
M. extens. indicis
M. extensor metacarpi pollic.
M. extensor primi internod.
M. extens. long. poll.
M. ext. secund. internod. poll.
M. abduct. digit. min.
M. inteross. dorsal. I. and II.
M. inteross. dorsal. III. and IV.

PLATE III.

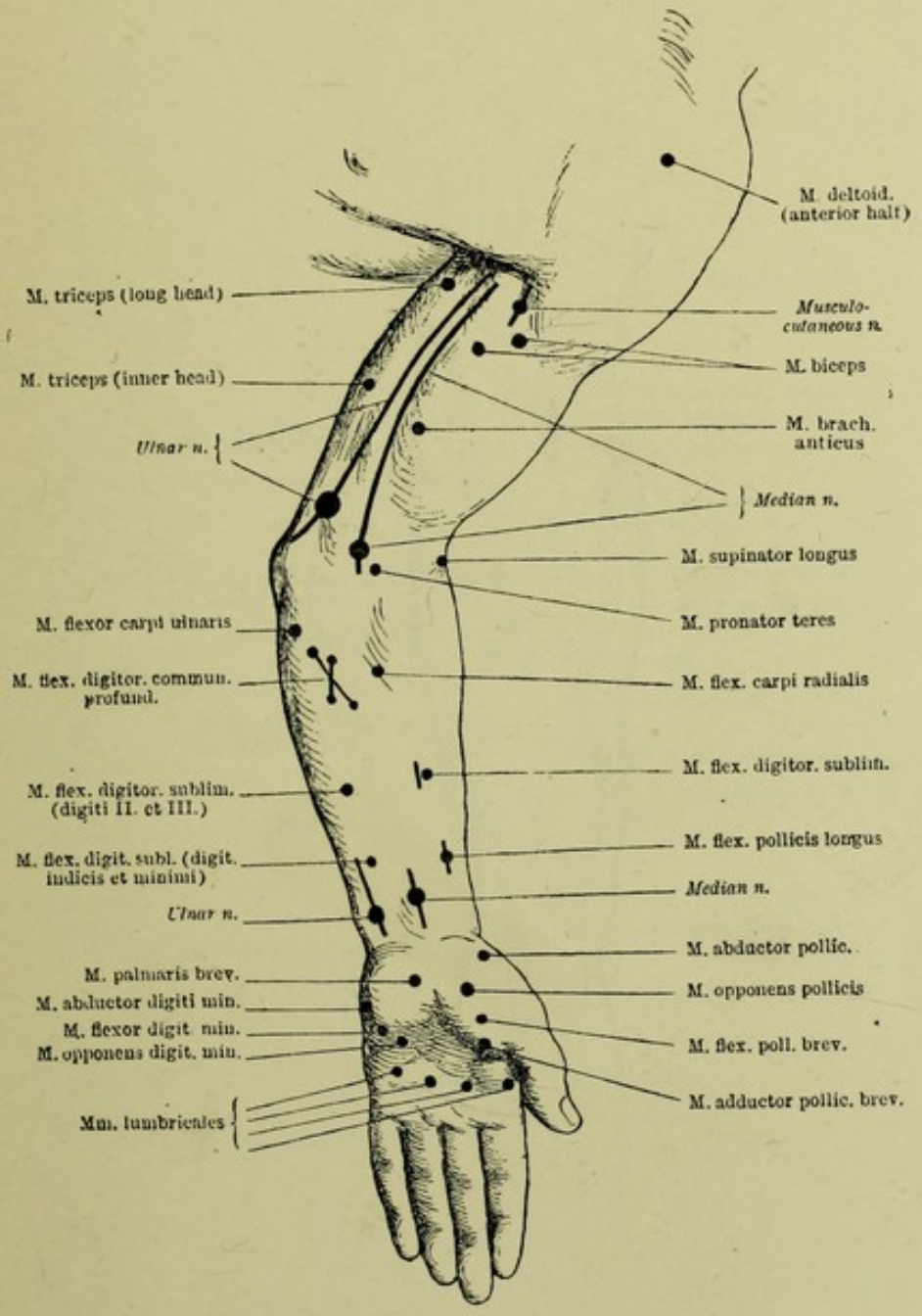

M. deltoid. (anterior halt)
M. triceps (long head)
Musculo-cutaneous n.
M. biceps
M. triceps (inner head)
M. brach. anticus
Ulnar n.
Median n.
M. supinator longus
M. pronator teres
M. flexor carpi ulnaris
M. flex. digitor. commun. profund.
M. flex. carpi radialis
M. flex. digitor. sublim.
M. flex. digitor. sublim. (digiti II. et III.)
M. flex. pollicis longus
M. flex. digit. subl. (digit. indicis et minimi)
Median n.
Ulnar n.
M. abductor pollic.
M. palmaris brev.
M. opponens pollicis
M. abductor digiti min.
M. flexor digit. min.
M. flex. poll. brev.
M. opponens digit. min.
M. adductor pollic. brev.
Mm. lumbricales

PLATE IV.

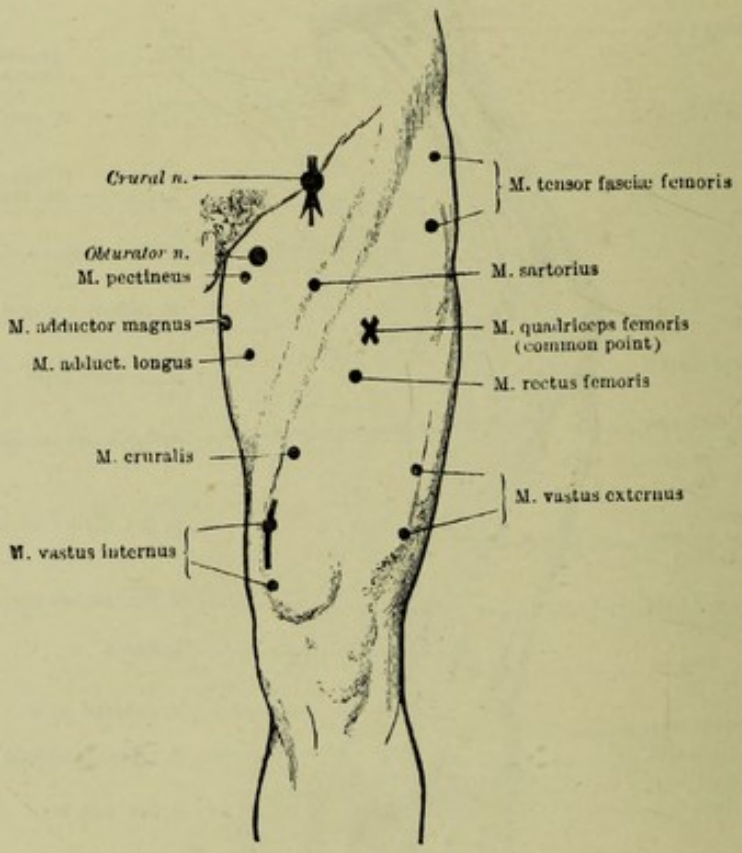

Crural n.
Obturator n.
M. pectineus
M. adductor magnus
M. abduct. longus
M. cruralis
M. vastus internus
M. tensor fasciæ femoris
M. sartorius
M. quadriceps femoris
(common point)
M. rectus femoris
M. vastus externus

PLATE V.

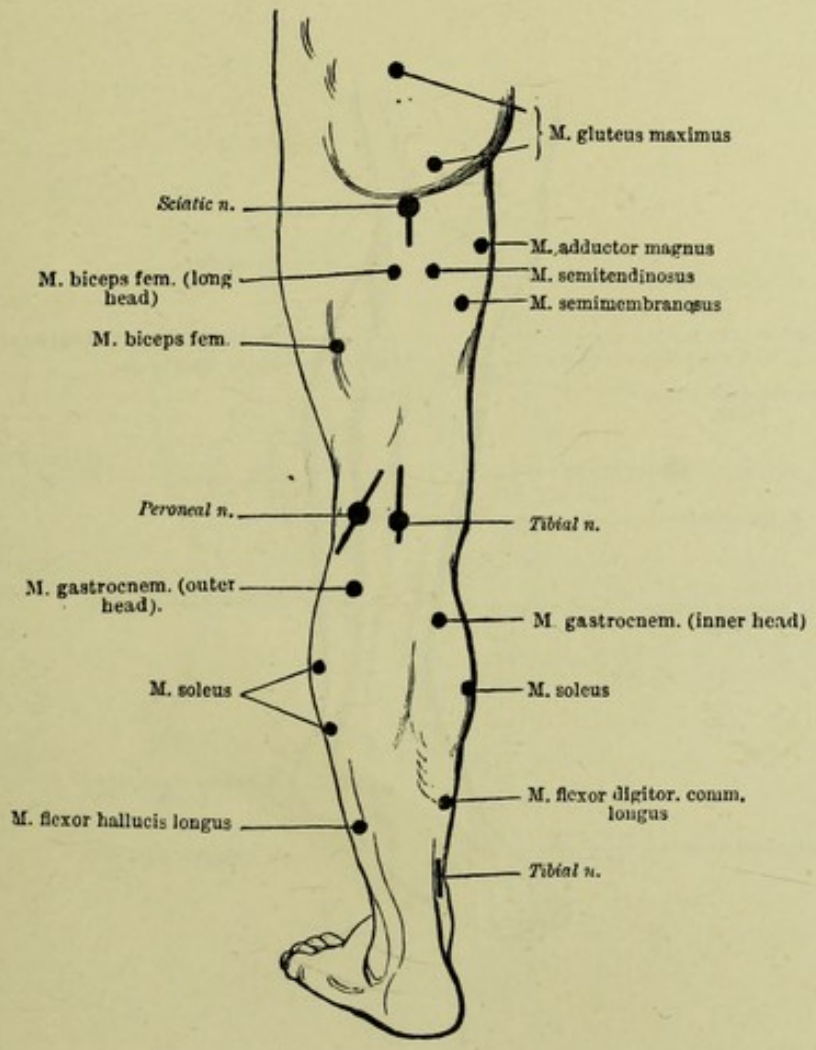

M. gluteus maximus
Sciatic n.
M. adductor magnus
M. biceps fem. (long head)
M. semitendinosus
M. semimembranosus
M. biceps fem.
Peroneal n.
Tibial n.
M. gastrocnem. (outer head).
M. gastrocnem. (inner head)
M. soleus
M. soleus
M. flexor digitor. comm. longus
M. flexor hallucis longus
Tibial n.

PLATE VI.

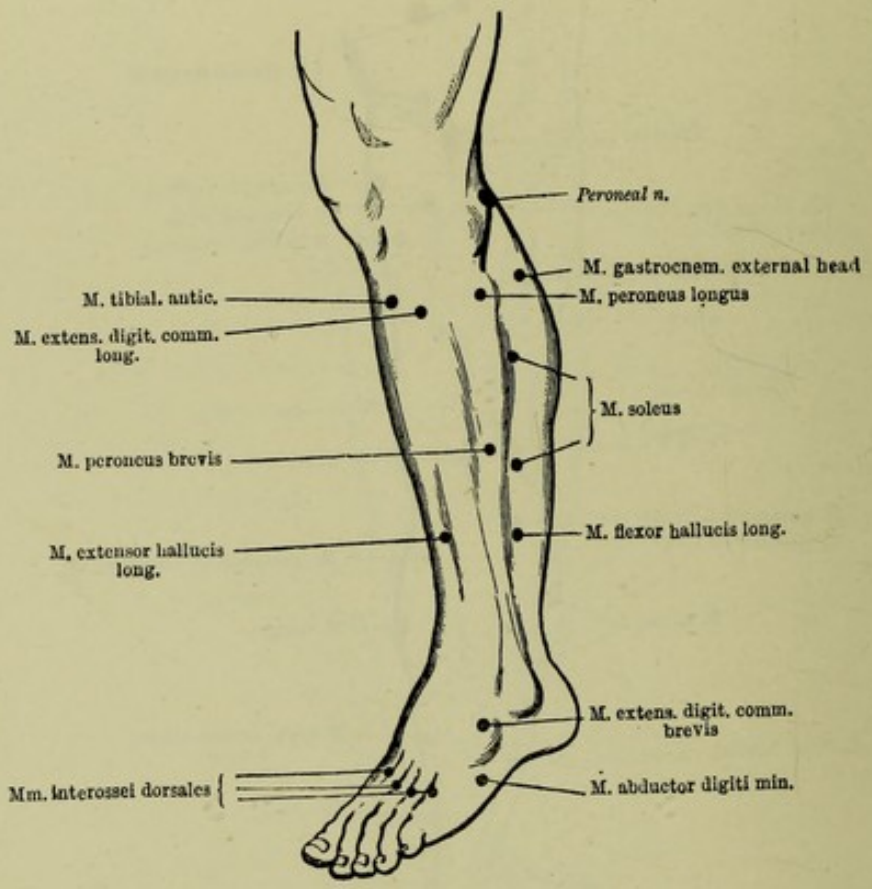

Peroneal n.
M. gastrocnem. external head
M. peroneus longus
M. tibial. antic.
M. extens. digit. comm. long.
M. soleus
M. peroneus brevis
M. flexor hallucis long.
M. extensor hallucis long.
M. extens. digit. comm. brevis
Mm. interossei dorsales
M. abductor digiti min.

PLATE VII.

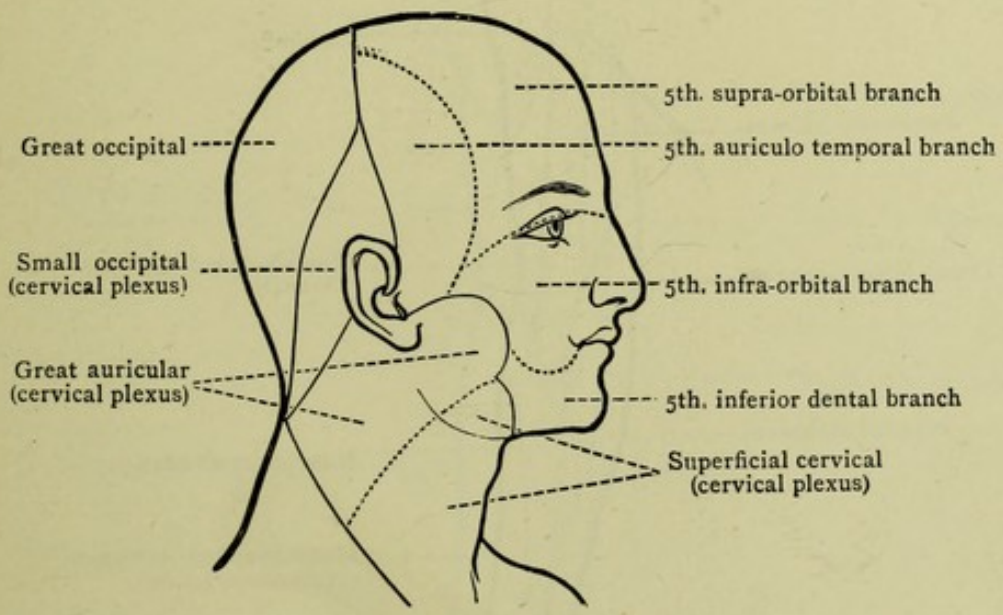

5th. supra-orbital branch
Great occipital
5th. auriculo temporal branch
Small occipital
(cervical plexus)
5th. infra-orbital branch
Great auricular
(cervical plexus)
5th. inferior dental branch
Superficial cervical
(cervical plexus)

PLATE VIII.

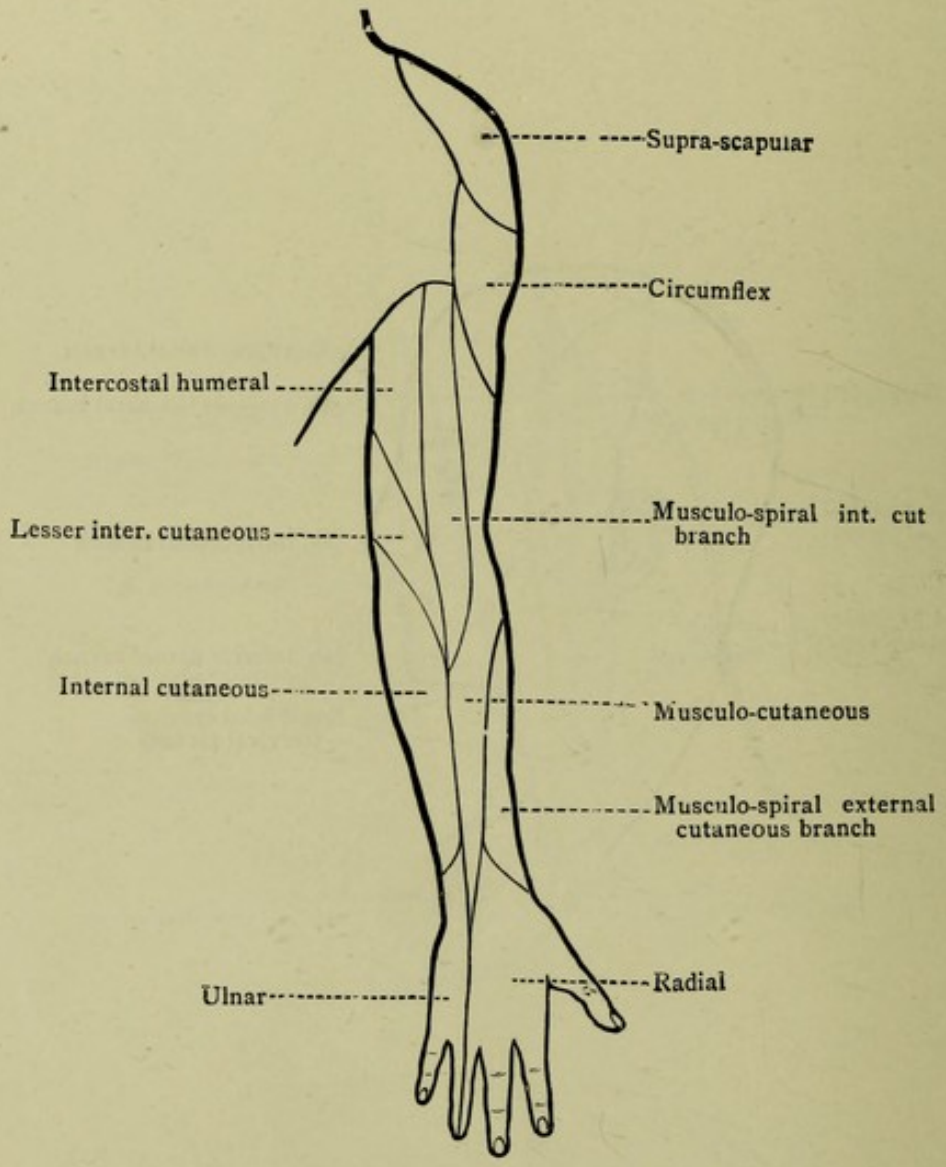

Supra-scapular
Circumflex
Intercostal humeral
Musculo-spiral int. cut branch
Lesser inter. cutaneous
Internal cutaneous
Musculo-cutaneous
Musculo-spiral external cutaneous branch
Radial
Ulnar

PLATE IX.

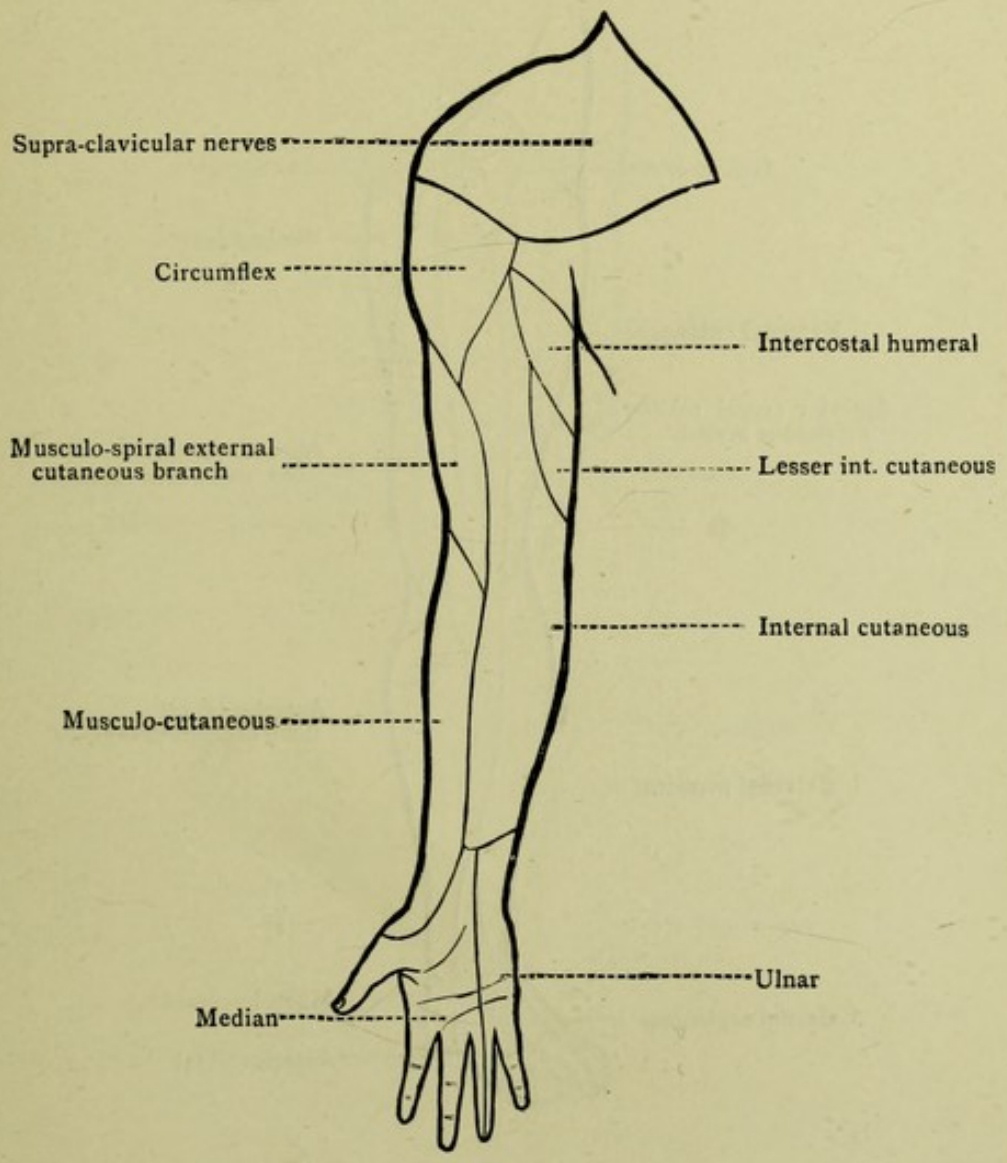

Supra-clavicular nerves
Circumflex
Intercostal humeral
Musculo-spiral external cutaneous branch
Lesser int. cutaneous
Internal cutaneous
Musculo-cutaneous
Ulnar
Median

PLATE X.

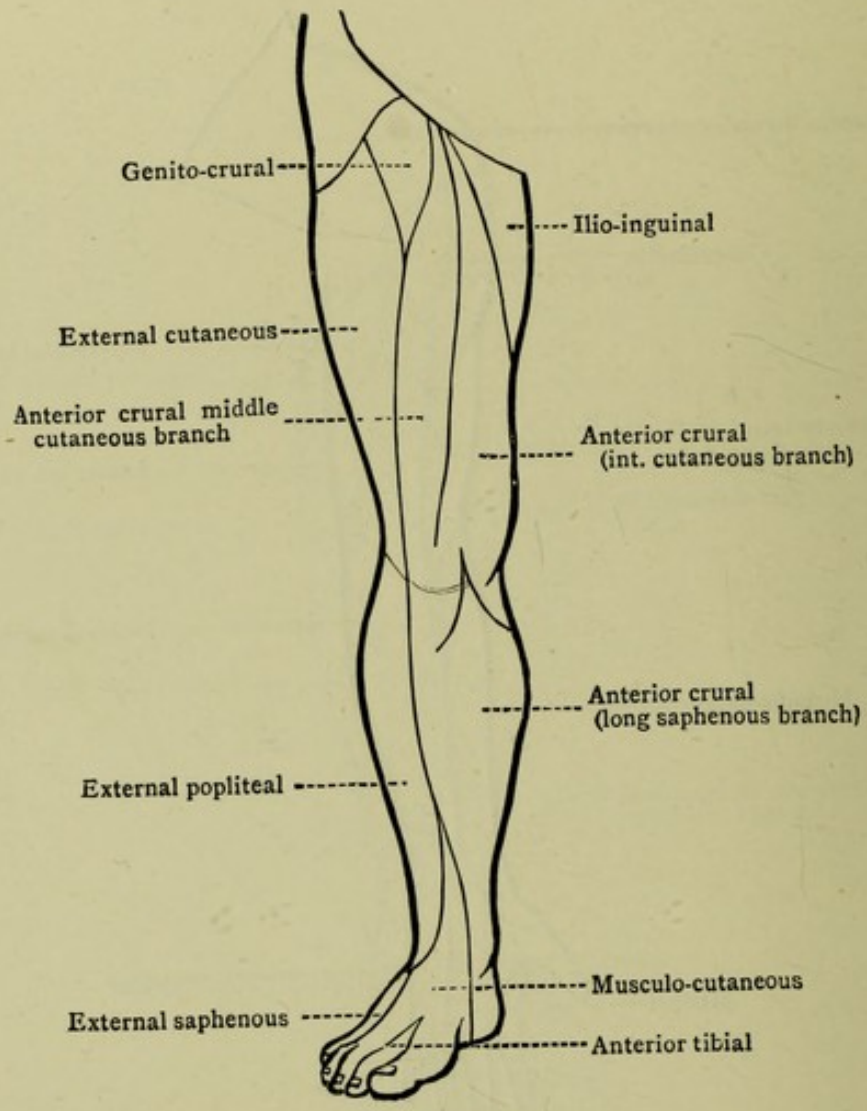
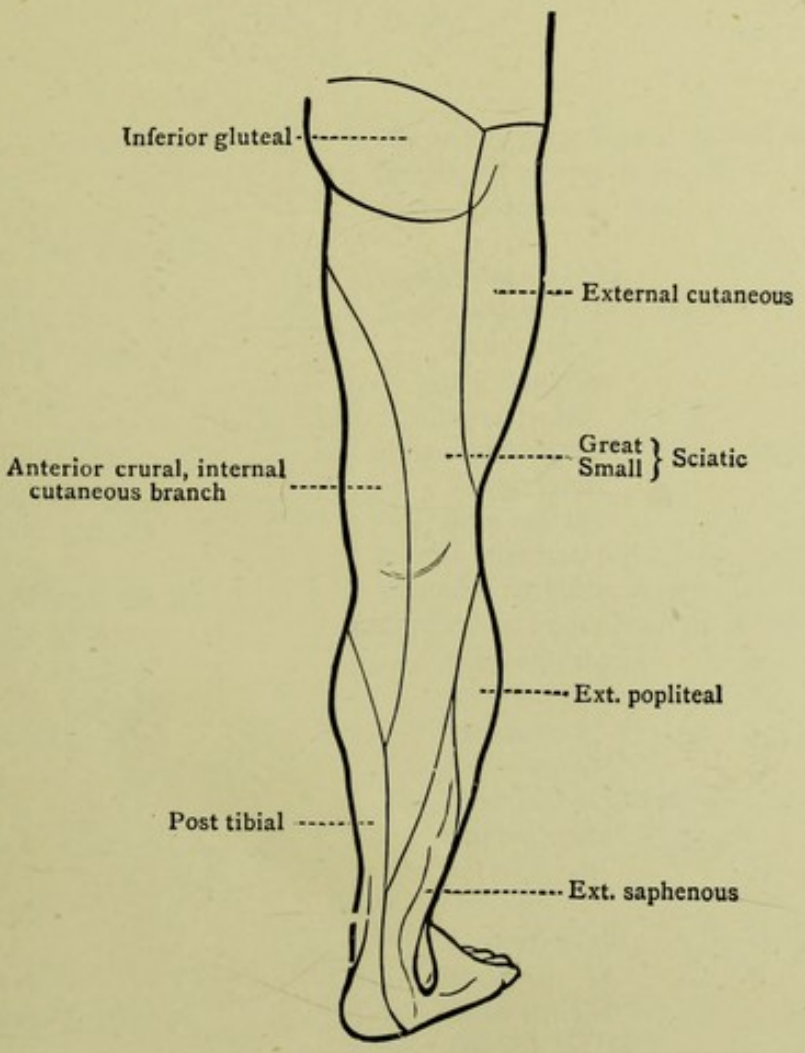

Genito-crural
Ilio-inguinal
External cutaneous
Anterior crural middle cutaneous branch
Anterior crural (int. cutaneous branch)
Anterior crural (long saphenous branch)
External popliteal
Musculo-cutaneous
External saphenous
Anterior tibial

PLATE XI.


Inferior gluteal
External cutaneous
Great
Small
Sciatic
Anterior crural, internal cutaneous branch
Ext. popliteal
Post tibial
Ext. saphenous

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