ELECTRICITY

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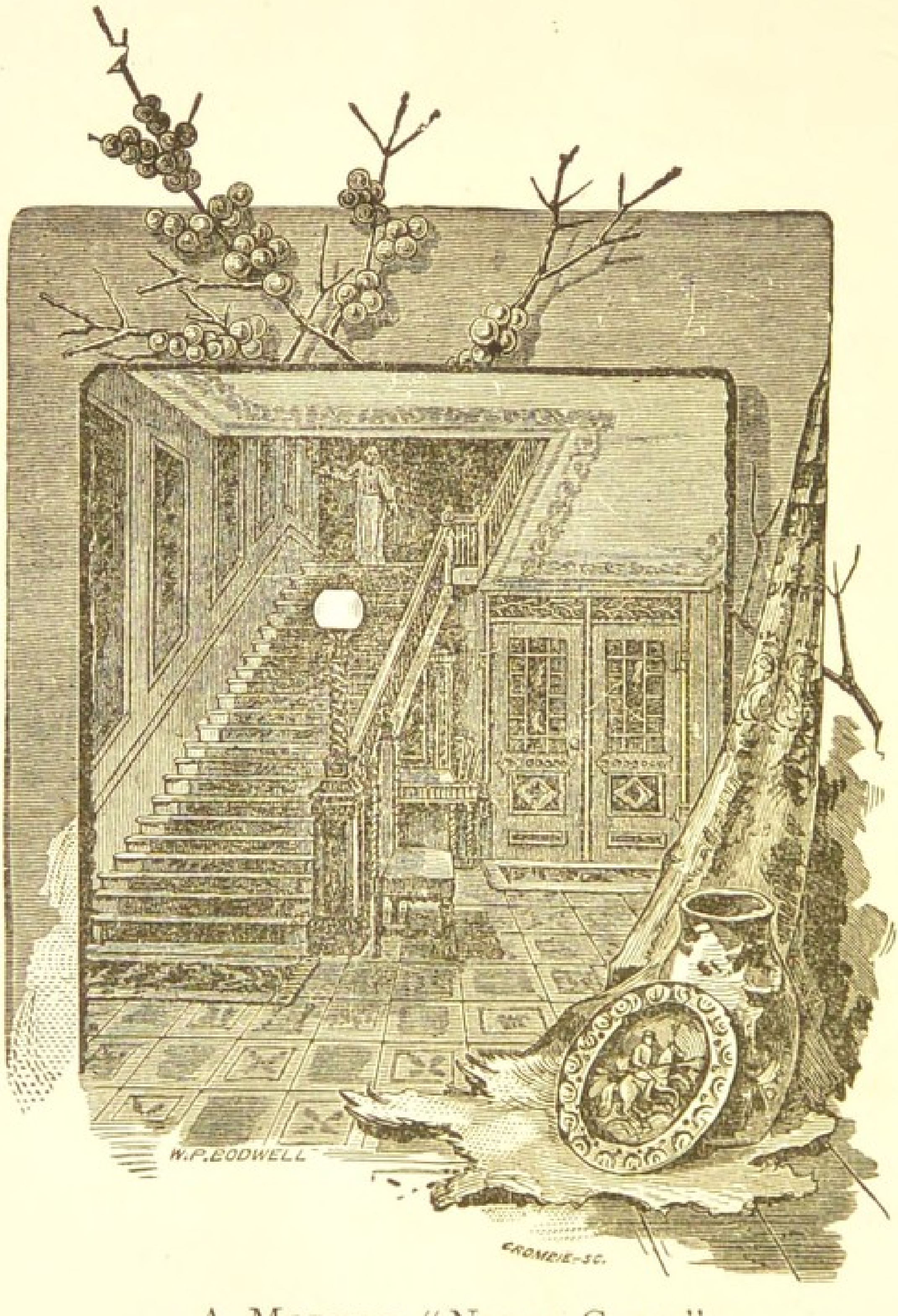

A MODERN "NIGHT-CALL."

ELECTRICITY

Its Application in Medicine and Surgery.

A Brief and Practical Exposition of Modern Scientific
Electro-Therapeutics.

— BY —

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This little book is, by permission, respectfully dedicated to

FRANCIS E. NIPHER,

Professor of Physics in Washington University, whose unselfish devotion to the cause of science has commanded the author's admiration and respect.

CHAPTER I.

INTRODUCTION.

The writer, having, without doubt, devoted an unusual amount of time and study, not only to electro-therapeutics, but also to original experimental research in general electrical science, rendering himself thoroughly conversant with electrical engineering in all its branches, even to such an extent as to have introduced the electric railway and the electrical transmission of power into this country, as well as assisted in familiarizing electrical engineers with the principles involved in the scientific design and construction of commercial electro-dynamic and dynamo-electric machinery, will perhaps be pardoned for assuming what to many will appear a somewhat dogmatic attitude in this brief exposition of the science of electro-therapeutics. In dealing with a subject covering so much ground, with the brevity that the confines of the present work demands, one must, however, speak to the point and authoritatively, avoiding all lengthy discussions and descriptions of the highways and byways leading to the conclusions enunciated. Should the statements of the writer be questioned, recognized authorities must be consulted.

The "medical electrician," and the average "electro-therapeutic text-book," have long since become the butt of amusement and laughing-stock of the physicist and electrical engineer. This condition of affairs is fully merited, and results from the unscientific methods of discussion and investigation that have thus far characterized the crude development of this most important, but sadly neglected branch of legitimate medicine. The most fallacious ideas have prevailed concerning the nature of electricity and the laws governing its manifestations. The failure to use proper instruments of precision has given rise to the most contradictory reports from the same and different operators as to the merits of electricity in the various pathological conditions which come under the observation of the physician. The rank and file of the profession who have undertaken to use it as a remedial agent have paid no attention whatever to the *technique* of the science, and the same may even be said of many of those savants who have made some considerable study of electro-therapeutics. To undertake the practice of electro-therapeutics without a thorough knowledge of the fundamental principles and laws of the science of electricity and magnetism, is as ridiculous and impracticable as would be an effort to carry on chemical analyses without having first become conversant with the principles of chemistry. In no science is a knowledge of general principles and natural laws so essential at every step as in the case of electrical science. Its laws are multiple, varied and complex, and a thorough under-standing of them is necessary for a correct interpretation of the numerous phenomena which are ever and anon manifesting themselves. It is no uncommon thing to see a physician dodging around with a stereotyped form of "medical battery" in his hand, proposing to destroy hair follicles by electrolytic action through the agency of a Faradic current; neither is it an unusual occurrence to hear the "medical electrician" refer to the negative and positive pole of a Faradic battery, and to speak of Static, Faradic and Galvanic electricity, as though they were all separate and distinct entities. In their conception of the various properties or qualities of an electric current, such as intensity, tension, and quantity, we find them equally at sea, and therefore constantly misapplying these terms. Many of these criticisms may be applied to some of the more modern writers upon the subject who speak very glibly about *ohms*, *volts* and *milli-amperes*. The methods of the past have been purely empirical, and therefore uncertain and varied results have been chronicled, until it is a wonder the science has any standing in legitimate medicine. The high esteem in which it is to-day held by the leading members or the medical profession, results from a forced recognition of the numerous accidental but brilliant results which have occasionally been stumbled upon, and not from any published uniformity of action. Electricity, however, is a definite quantity capable of producing with uniformity, certain physical, chemical and nutrient changes, whenever we come to understand the laws governing its action, and learn to apply it with methods of precision.

A few writers of very recent date, more particularly in the field of gynæcological electro-therapeutics, have approached nearer to a scientific exposition of the subject. I refer especially to the writings of Apostoli, Tripier, Engelmann, and Massey. Much of the existing empiricism has resulted from the absence of, and failure to use, suitable and reliable measuring instruments. Progress in every department of science is largely dependent on exact measurements, since it is only by this means that we obtain an accurate knowledge of relative values. The thermometer enables us to investigate the the laws of heat; the barometer furnishes a knowledge of atmospheric pressure and the various matters relating to it. In chemistry and astronomy, almost every step depends upon such measurement. Even our ordinary business transactions, and the value of our currency, are regulated by the common scales by which we measure the force of gravity. Electric science is no exception to this rule. We require to know, accurately, relative differences of potential and current strength; the conductivity and resistance of various substances and tissues; the force of electric attraction and repulsion; the comparative energy of the various instruments used for generating and accumulating electricity; and other matters of equal importance.

Electric measurement, however, presents peculiar difficulties not met with in the measurement of other forms of energy. In the measurement of gravity, we deal with a force easily controlled, the direction of whose movement is always known, and which, on the various points of the earth's surface, is subject to but slight variation; in heat we have an energy suscepti ble of easy control, its movement is slow, and its direction easily ascertained. Electricity, on the other hand, moves with greater rapidity than thought; its direction is difficult to ascertain, and it is not readily subservient to absolute control; so that the results of measurement, by even some of our best constructed instruments, fall short of what we would desire. Any very great inaccuracy of measurement, however, is worse than no attempt at measurement. The physician who imagines that he can deal with electricity as a remedial agent and secure anything approximating uniform results, without the use of reliable measuring instruments, will find himself as much at sea as the mariner without his compass, the carpenter without his rule, or the pharmacist without his scales.

The ignorance which prevails concerning the physics of the subject can be illustrated in no better way than by citing the fact that the writer has frequently been applied to by brother practitioners who wished to know what form or kind of battery would be best for all purposes, since their means were limited and they could afford to purchase but one. Let us imagine a would-be pharmacist applying to us to know what would be the best single drug to place on sale in a prospective drug store, which would be likely to meet all cases and emergencies, in lieu of his being obliged to assume the expense of a stock comprising a varied assortment of drugs. What would be our answer to such an applicant? Must we not condole his lack of means, and advise him to enter upon the pursuit of some business more commensurate with his capital? The one proposition is no more absurd than the other.

CHAPTER II.

ELECTRICITY AND MAGNETISM.

The Condition of Electrification is a peculiar and unusual property which most forms of matter may assume under certain specific conditions, rendering the matter so electrified susceptible of manifesting peculiar and unusual phenomena. For instance, if two sheets or pieces of dissimilar metal, such, for example, as copper and zinc, be immersed in an acidulated solution and connected together metallically, the metallic connection will assume a property which it did not before possess, the condition it will assume being that of "electrification." In other words, what is called an "electric current" will flow through the connecting metal or through the wire, in case the connecting metal assumes that form. Under this condition, the wire is capable of manifesting many strange phenomena. For instance, it will possess the power, which it did not have before, of attracting iron filings, and, if it be placed over and parallel with a delicately suspended light magnet, such as the needle of a compass, it will cause the needle to turn on its axis and place itself at right angles to the wire. If this same wire be coiled into a spool, or "helix" as it is technically termed, such spool, when suspended freely, will assume a directive force, such as will place it in the line of the magnetic meridian of the earth, which corresponds very nearly with the geographical axis, and that end which points to the North we call the north pole of such helix, although in reality it is the south pole, because, unlike magnetic poles attract each other, while like poles repel each other. If this same spool be thrust into iron filings, a great number of such filings will collect around each end of the spool, and this marks the position of what is termed the "poles" of the helix. Such a spool will also have the power to attract to itself small pieces of iron and steel, when brought sufficiently near such substances. Again, if we insert into the middle of this spool, a piece of *soft* iron, the latter takes upon itself that property which is termed "magnetism," so long as the so-called "current of electricity" continues to flow, or, in more exact words, so long as the wire which goes to make up the spool remains in the condition of electrification; the moment the current ceases to flow, or the wire loses this peculiar property which we call electrification, the magnetism of the iron also ceases, or, as it is technically termed, the iron becomes "demagnetized." If, in place of a piece of soft iron, we were to insert into the centre of this helix, a piece of *hard* iron or steel, the latter would become permanently magnetized; that is to say, the steel will not lose its magnetism so soon as the current of electricity ceases to flow through the wire, but will become a "*permanent*" magnet. A spool of wire such as we have described with a piece of soft iron in its centre, is technically known as an "electro-magnet." Electro-magnets are to be found in all telegraph sounders, telephone receivers, electric bells, electric light generators, and, in fact, in nearly every piece of electro-mechanism.

WHAT IS ELECTRICITY; or by virtue of what peculiar state of affairs does this condition of electrification exist? This is a question which has for ages in the past challenged an answer from those most learned in the science of natural philosophy. Various theories have waxed and waned. The single- and the double-fluid hypotheses, with others, have, each in their turn had their day and coterie of adherents, only to be finally consigned to a place amongst the myths of the past. Now, however, what we call electricity has come to be looked upon by nearly all the leading scientists of the present age, as having no existence *per se*, apart and distinct from the matter which it affects; in other words, as being in no sense a distinct entity like a gas or liquid, but rather as being one of the many forms of energy, a simple mode of motion or molecular vibration, similar to light, heat, and sound, into all of which it is convertible, subject to the laws governing the correlation and conservation of physical forces. All of the various forms of energy—heat, light, sound, chemical action, and electricity—are interconvertible one with the other. Unlike sound, heat, and light, however, the molecular vibration which accompanies or gives rise to the manifestation of electric energy, assumes a certain directive force, which it also has the power of impressing upon surrounding matter. Under this conception of the nature of electricity, and other theories based upon it, have been developed the various industrial applications of electricity to their present marvelous state of perfection. In the case of electric generators and electric-light machines, for instance, we are now no longer dependent upon empirical methods, upon rules of thumb, and upon traditional practice, as in the past. It is not even sufficient now to be able to make one particular kind or type of such machine so that it will simply work, but we must also know how to construct all possible varieties with the highest degree of perfection. For a long time our text-books and current electrical literature were filled with intricate formulæ, involving integral calculus and other difficult branches of higher mathematics, all of which involved the use of certain constants which had to be predetermined for each particular machine and for each particular type of machine. There were no generalizations, no universally applicable formulæ, no general constants, so that these formulæ were practically useless, and the electrical engineer was compelled to resort to rules of thumb and traditional practices —much of the same state of affairs existing as we now find in electro-therapeutics. To-day, however, it is quite different. We can now with mathematical precision calculate the best size, shape, and exciting power of a pair of "field magnets" for such machines, and the exact speed at which a given machine must be run to produce a certain electric output. To do this, however, we are obliged to resort to other laws and to other theories than those enunciated by Lenz, Jacobi, Dub, Muller, and others, in the past, concerning magnetism.

For those formulæ and theories upon which we rely to-day, we are indebted to Frohlich, Deprez, Thomson, Hopkinson and Kapp, who, by their conceptions and theories, have so unravelled the mysteries and fundamental principles of dynamic electricity, as to render it possible at this day to construct an almost theoretically perfect piece of electric apparatus. The present state of this art is due almost entirely to that conception which looks upon both an electric current and a magnet as emitting what are called "*lines of force*," which, in their passage through different media, meet with a "*resistance*" proportionate to, and dependent upon, the character of the matter they traverse. Whether such lines do really exist or not, is of but little moment for our purpose, since it suffices to know that by means of iron filings we can make such lines visible and study their properties. According to this conception, every wire carying a current of electricity is surrounded by a multitude of circular lines arranged like concentric rings around the wire, thus (see Fig. 1), which lines gradually diminish in number as the distance from the wire increases. If we could have a *single* magnetic pole, that is, a piece of steel having only one

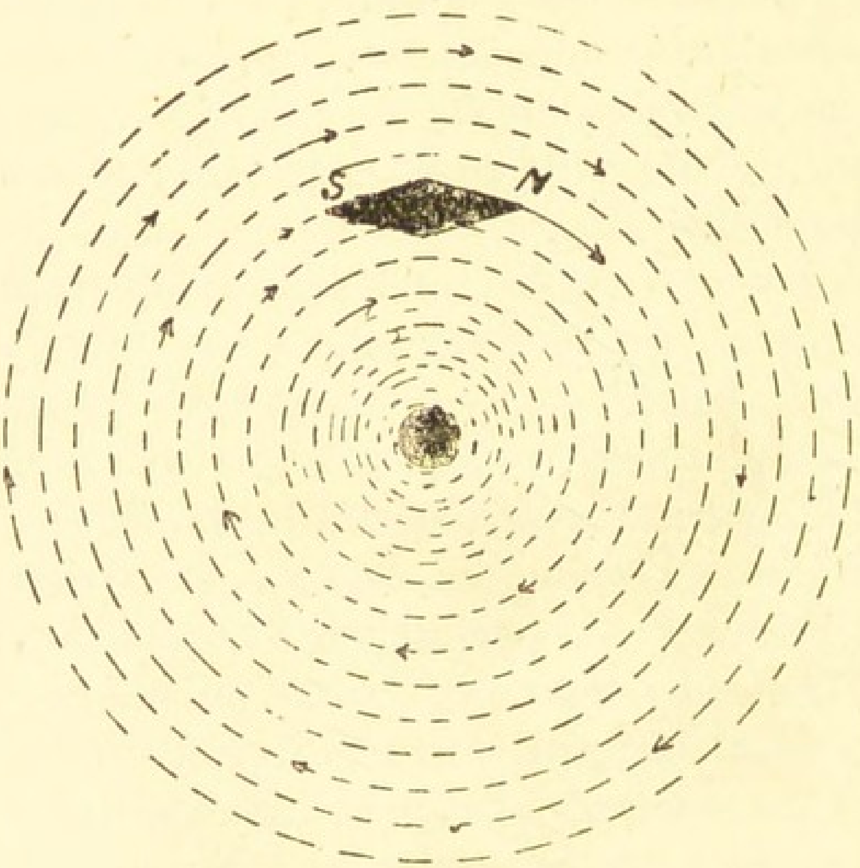

FIG 1.

pole, and that a north pole, for instance, this pole would, if brought near a wire carying a current of electricity, revolve around the wire; but since a magnet with only one pole is an impossibility, and since the same force which urges the north pole in one direction, would urge the south pole in the opposite direction, the magnet as a whole cannot revolve around a straight wire, but will set itself, as already stated, at right angles to the wire. In just what direction these lines of force run around the wire, we cannot say, but to fix our ideas we may consider those lines positive which would carry a north pole around the wire in the direction of the hands of a watch, if the observer sees the wire from the end, and if the current flows from the observer. If we place a piece of paper over such a magnet and at right angles to such a wire, the lines of force made visible by iron filings will now appear as somewhat distorted circles

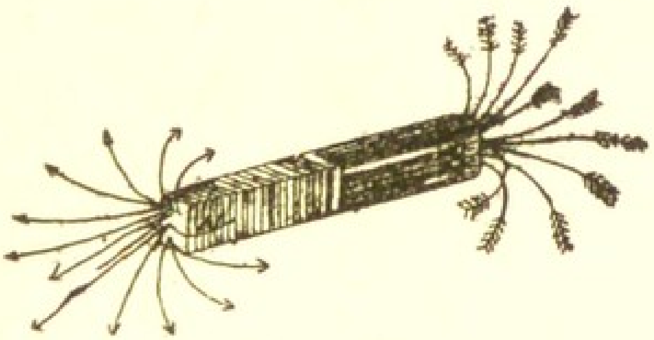

FIG. 2.

crowded densely into the poles of the magnet. Within the magnet they are not so well defined as upon the outside of it, but as near as can be judged from rough experiment, no lines are lost in the middle, the same number of lines that enter at one end of the magnet finding their way out at the other. This, then, explains why it is that we cannot have one free magnetic pole or a magnet with unequal poles. Whence it follows that every line of force must be a closed line, an open magnetic line of force, being as much of an impossibility as a continuous electric current in an open circuit. According to our conception, a positive line of force goes in the air from the north to the south pole, and in iron from south to north. If, instead of a steel or "permanent" magnet, we had

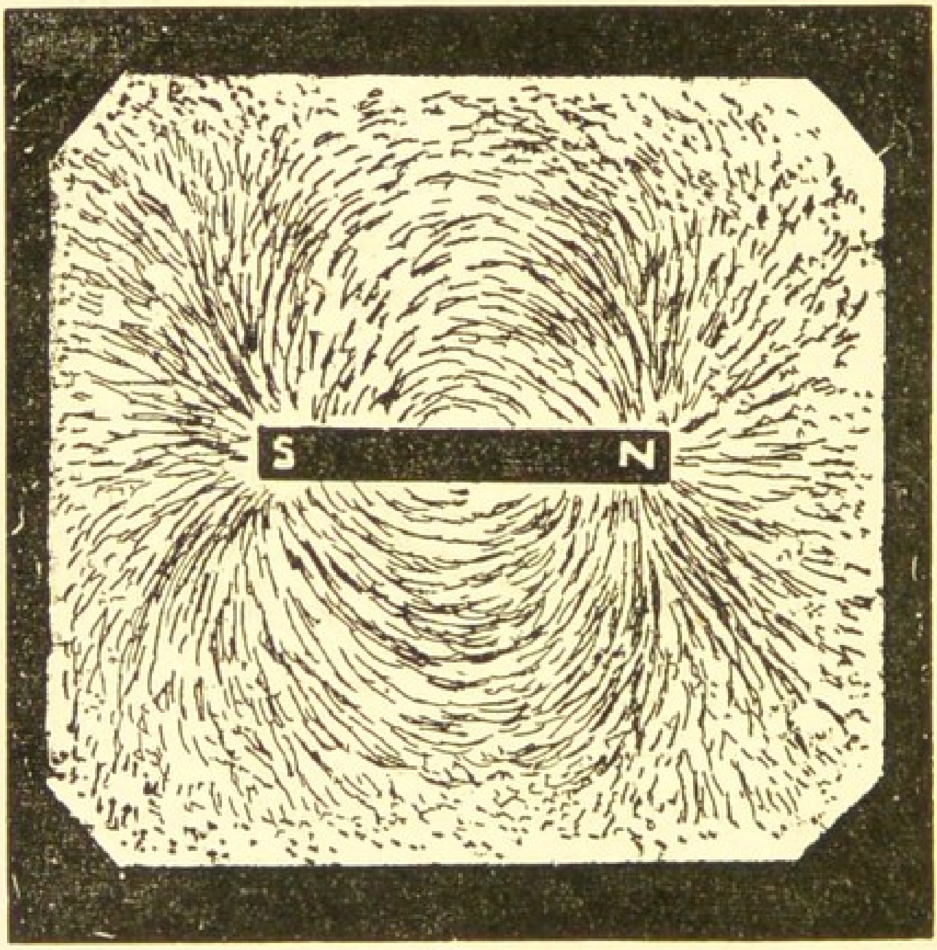

FIG. 3

experimented with a piece of soft iron, we should also find that through its presence the originally circular lines around the wire would have become somewhat distorted and crowded together at the ends of the piece of soft iron, which, like a steel magnet, will set itself at right angles to a straight wire carrying a current. The total number of lines made visible by filings would, under these circumstances, be considerably increased, even on the side

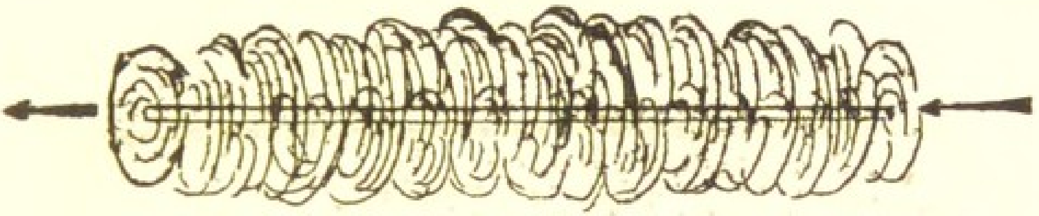

Fig. 4.

of the wire opposite to that occupied by the piece of iron; and if we should now increase the current, we would still further increase the number of lines, showing that the number of lines is dependent upon the strength of the current, and that one and the same current will yield more lines if a piece of soft iron be placed in its neighborhood, and also showing that the

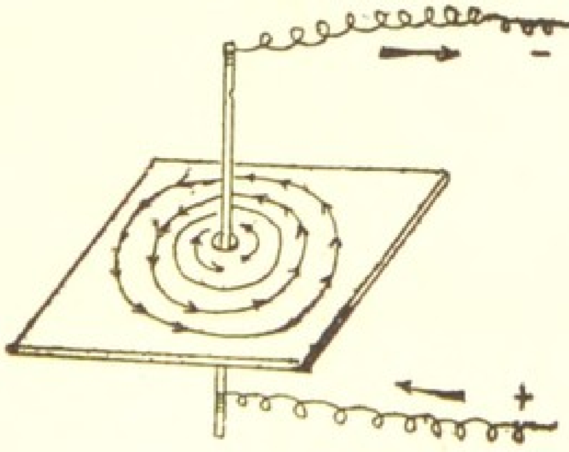

Fig. 5

lines pass more easily through iron than air. This latter circumstance leads us to the conception that every medium offers a certain *resistance* to the passage of these lines of force, and the inverse of that resistance is what is called the "*magnetic permeability*" of the medium, which, in the case of iron, is from 40 to 20,000 times as great as that of air. In other words, if we should surround this straight wire by a cylinder of iron, the same current would yield within that

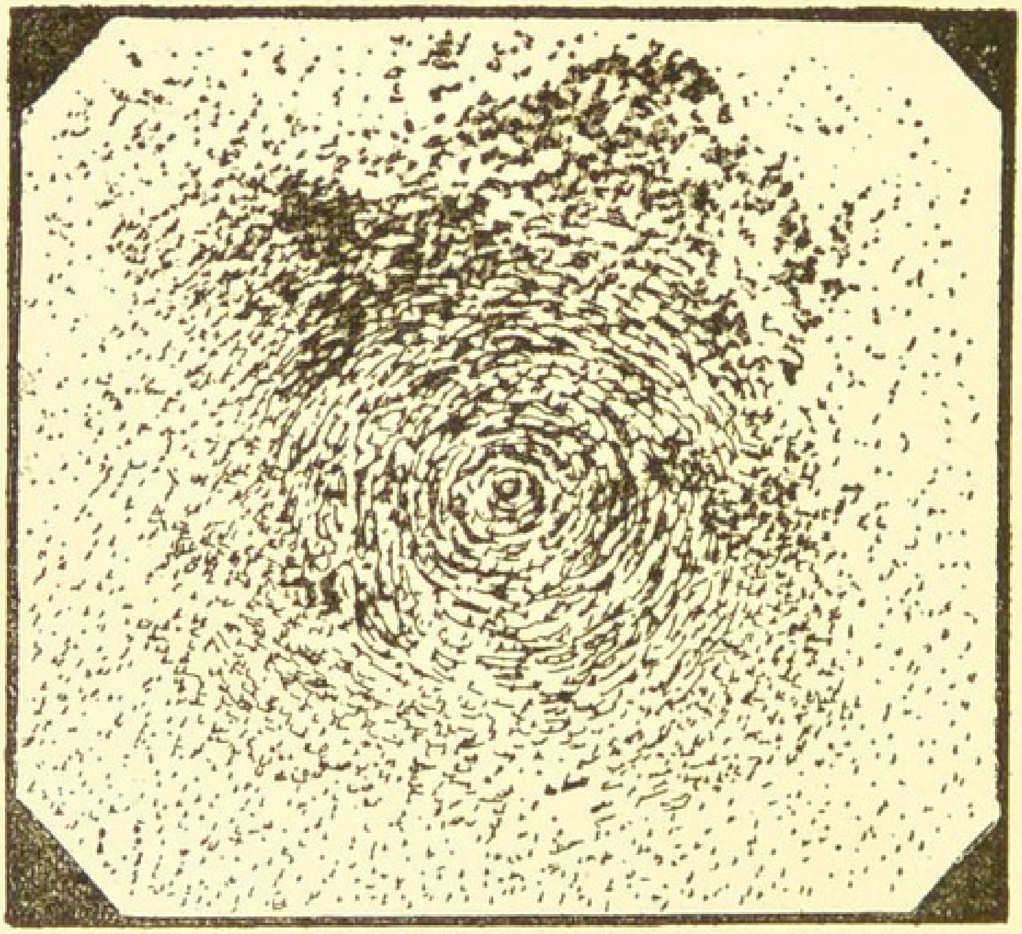

FIG. 6.

space, from 40 to 20,000 times as many lines of force as when the space contained only air. In the same way, any permanent magnet emits similar lines of force, which go through the magnet from the south to the north pole, emerging at the north pole and completing their circuit through the air by travelling from the north to the south pole, as here shown (see Fig. 2).

These lines of force are no fiction of the imagination like the lines of latitude and longitude on the globe; they exist and can be rendered visible by iron filings sprinkled upon a card held over a magnet, or having a wire carrying a current run through its centre at right angles to the plane of its surface. These ideas are shown very clearly and diagrammatically in Figs. 1, 2, 4, 5, and 7, and more beautifully and accurately in Figs. 3, 6, and 8, the latter being reproductions from Nature, showing experiments with iron filings. We see, therefore, that the electric current may be treated as a magnetic phenomenon, and that both in the case of a magnet and in that of a wire carrying a current, a portion, at least, of the energy exists outside of the magnet, or of the wire conveying the current, and must be sought in the surrounding space. It is supposed that these magnetic "*whirls*," or lines of force, are set up by movements, pressures, and tensions in the surrounding *Æther*, as the result of the peculiar molecular vibrations constituting or accompanying the electrification of the wire. With this explanation, we are now in shape to establish the relation between a current and a magnet, and to show how the one may produce the other.

When we wind a wire carrying a current, into a spool or helix, as before described, the magnetic whirls or lines of force in the surrounding space, are no longer small circles wrapping around each separate turn of the conducting wire, but the lines of adjacent turns of the wire forming the helix merge into one another, and run continuously through the helix from one end to the other, as here shown (see Fig. 7). Compare this figure with Fig. 2, and the similarity in the arrangement of the lines of force in a magnet is obvious. When we push a bar of iron into the interior of this helix, the lines of force will run through the iron and magnetise it, converting it

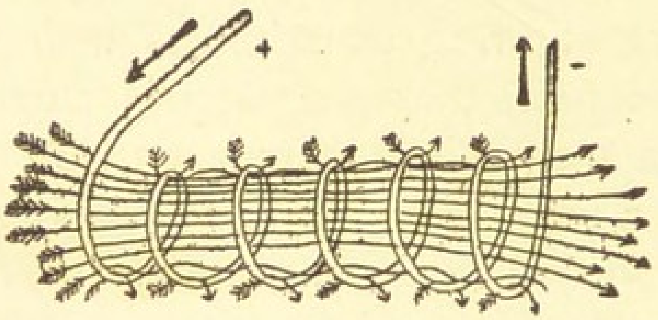

Fig. 7.

into an "*electro-magnet*," as shown in Fig. 8, where the the lines of force, or "*magnetic field*," as it is called, is shown as reproduced from the actual figure made by iron filings. Having now described how an electric current, or rather a wire under the condition of electrification, possesses for the time magnetic properties and is surrounded by lines of force, and further shown how magnetism can be produced from electric currents, we are naturally led to a consideration of the converse condition of affairs, and to assume that magnetism may produce electricity; for in Nature, wherever we find an action, there must we also find a reaction, and we are, therefore, led to assume that if magnetism is the accompaniment of the electric current and the threading of these lines of force through the helix, as in Fig. 7, then the threading of lines of force

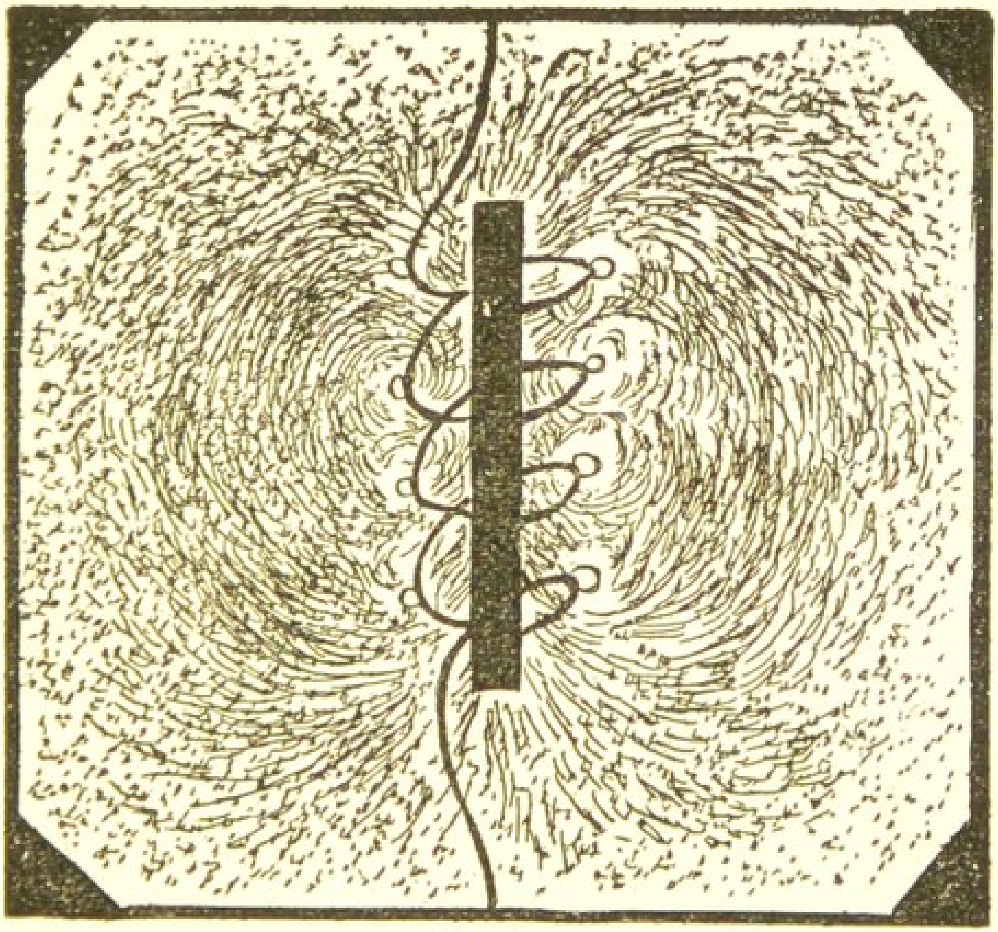

FIG. 8.

through a closed helix of wire, said lines being emitted by a magnet, should in turn produce an electric current. Such assumption is correct, and the act of introducing a magnet into the centre of such a closed helix or spool of wire will produce an electric current in the helix, since such act is accompanied by the passage of lines of force through and around said helix. This constitutes the principle upon which all magneto-electric generators are based, whether it be the Faradic coil or the electric light generator, and is known as the inductive method of generating currents.

We should now have a very correct and clear conception of the relationship between electricity and magnetism, and of the peculiar physical phenomena which accompany the manifestation of both.

THE METHODS OF MANIFESTATION of that condition known as electrification are many besides those of simple magnetism. Although electricity or electric energy cannot be felt or seen, it is nevertheless capable of manifesting itself, through the many *effects* which it can produce. These are of various kinds. They are magnetic, (which has already been considered), thermal, chemical and physiological. For instance, a current flowing through a wire will heat it, the amount of heat generated depending upon the relation between the volume or strength of current flowing, and the resistance or size of the wire; flowing over a magnetic needle it will cause the latter to turn, as we have already seen, the angle through which the needle is deflected being a measure of the volume or strength of the current flowing; flowing through liquids it decomposes them, the amount of decomposition produced in a given time being also a measure of the volume or strength of the current flowing; and lastly, flowing through the living body, or any sensitive portion of it, it produces certain peculiar sensations, as well as chemical and physical changes.

THE METHODS OF GENERATING ELECTRICITY or of setting up that condition of matter known as electrification, are numerous, and consist mainly of *induction*, *chemical action*, *thermal contact* of different metals, and *friction*. In electro-therapeutics we have to deal principally with the chemical and inductive methods.

THE TWO QUALITIES OF AN ELECTRIC CURRENT.—Electricity possesses two qualities, that of "*pressure*" and that of "*volume*" or "*strength*." With the nature of these qualities once clearly in mind, the whole science and its involved phenomena immediately become clear. For the purpose of securing a definite, tangible conception of the nature of an electric current, therefore, it may be likened to a current of water flowing through a pipe, and we can illustrate its behavior by pointing out its analogy in hydraulics. Any device for generating electricity, such as a Galvanic battery, a thermo-electric pile, or magneto-electric or dynamo-electric machine, is essentially a pump, which pumps electricity instead of water. If the discharge pipe of a hydraulic pump be carried around through a given circuit and connected into the suction side, both pump and pipe being full of water, the movement of the pump will cause the water to flow in one particular direction, producing a "*continuous current*" of water. Substitute a Galvanic battery or a continuous current electric light generator known as a "*dynamo*" for this hydraulic pump, wire for the pipe, and electricity for the water, and we have a conception of an electric current at once clear and tangible as to all of its elementary phenomena. Let us now place within brackets those electrical terms which are analogous to the terms used in hydraulics, and it may be said that a certain number of pounds [*volts*] of pressure is required to overcome the friction [*resistance*] of the pipe [*wire*] in order that the water [*current*] may flow at the rate of so many gallons per minute [*amperes*]. The larger the pipe [*wire*] the more water [*current*] can be carried, and the less will be the friction [*resistance or drop*]; or, *per contra*, the smaller the pipe [*wire*] the less the quantity [*amperes*] per minute, and the greater will be the friction [*loss or drop*]. It is at once evident, then, that the pipe [*wire*] might be so small that the friction [*resistance*] would absorb a very large proportion of the power of the pump [*dynamo or battery*], leaving but little remaining for useful effect. Let us carry this illustration of a hydraulic pump circulating or pumping water through a continuous main pipe still further, and assume that at various points in this main, water motors are introduced. Motors thus located would be said to be in "*series*," *i. e.*, arranged like beads on a string, one after the other (see Fig. 9). It is apparent that when the pump is started and the current begins to flow, the motors will also begin to move, but the pressure developed by the pump must of necessity be equal to the number of pounds pressure required to move each motor or to force the current through each motor, multiplied by the number of motors, in addition to the pressure required to overcome the loss in the main pipe by friction; that is to say, if the frictional resistance of the main pipe is

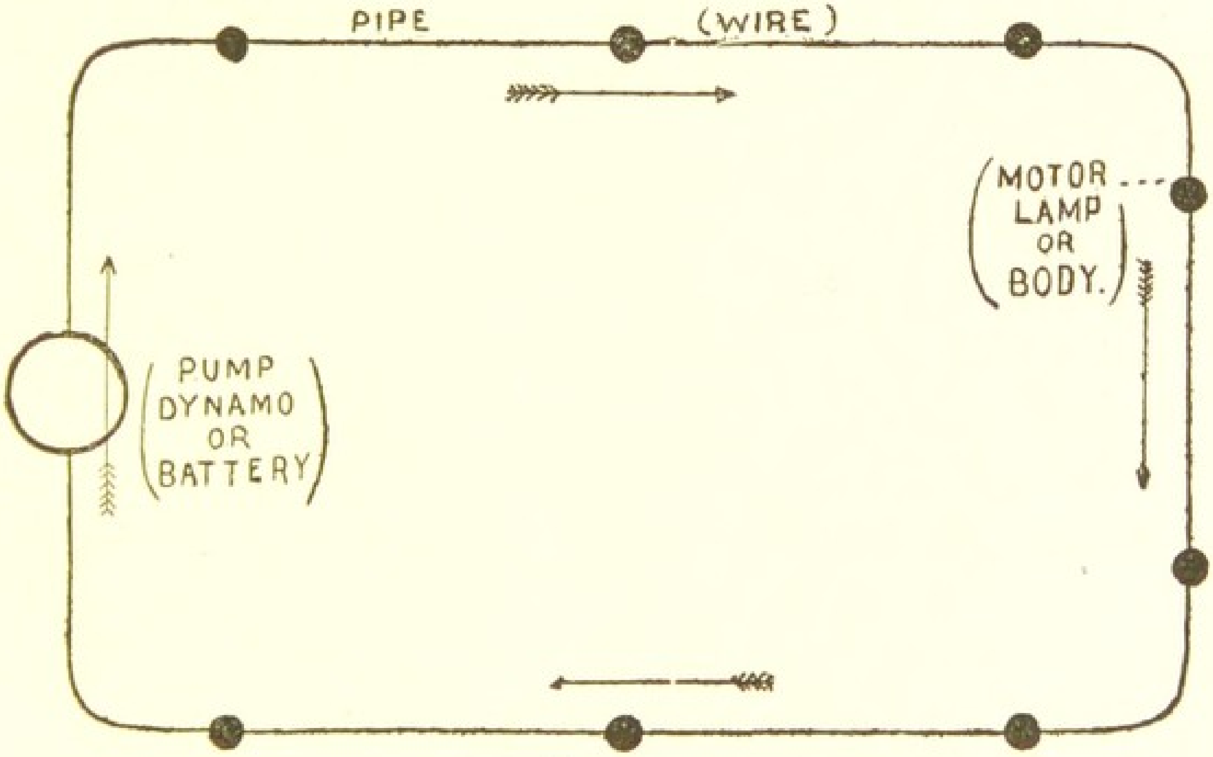

Fig. 9.

equal to ten pounds pressure, and we have a series of eight motors each requiring two pounds pressure to operate them, the gross pressure to be developed by the pump must be equal to $2 \times 8 + 10 = 26$ pounds total pressure. This condition of affairs corresponds exactly to an electric circuit through which it may be desired to send a current of electricity, and in which the water motors may be replaced either by electric motors, electric lamps, or human beings or portions of the latter, assuming them all to be in series. We see, therefore, that it is by virtue of that quality which we term pressure in hydraulics, that we are enabled to force a current of electricity through any electric circuit and overcome the latter's resistance. In electric science we use the term "*electro-motive force*" to designate the pressure or head under and by virtue of which an electric current circulates. This electro-motive force is created by reason of what is called a "*difference of potential*" across the two sides of the source of the electric current, whether this be a Galvanic battery, a dynamo, or some other form of electric generator. This difference of potential corresponds to what is called a difference of level in hydraulics, or to a difference of temperature in thermo-dynamics. If, for instance, two vessels filled with water, be connected by means of a pipe, and one vessel be placed at a higher level than the other, a current of water will flow through the connecting pipe from the higher vessel to the lower one; and, so again, in the case of two bodies in which there exists a difference of temperature, if these be so placed that heat can pass from one to the other, heat will pass from the hotter to the colder as long as any difference of temperature exists. In like manner, a current of electricity will flow from a higher or "*positive*" potential to a lower or "*negative*" potential so long as there exists a difference of potential, and the degree of electro-motive force which urges a current forward will depend upon the extent of the difference of potential which exists between the two sides of the source of supply or between the positive and negative poles of any form of generator. A difference of potential in electricity is, therefore, analogous with difference of pressure in gases, with difference of level in liquids, and with difference of temperature in heat.

Now, just as we use the pound as a unit of measure of pressure in hydraulics, so do we use the unit known as the "*Volt*" as a unit of measure of electro-motive force in electricity. The standard value of the unit being that electro-motive force which will establish or circulate a current of electricity of one "*Ampere*" through a resistance of one "*Ohm.*"* This naturally brings us to inquire into the nature and value of these two last mentioned units, the "*ampere*" and the "*ohm.*" The "*ampere*" is the unit of measure of the "*volume*" or "*strength*" of a current, which latter is directly proportional to the amount of chemical decomposition produced by the current in a given time, the standard value of the unit being represented by that current which will deposit 0.00111815 gramme, or 0.017253

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* A Daniell element or battery, especially prepared for this purpose, for example, has an electro-motive force of 1.079 volts, while a Latimer Clark's standard cell, which is very constant on open circuit, has an electro motive force of 1,457 volts.

grain, of silver per second on one of the plates of a silver "*voltameter*," the liquid employed being a solution of silver nitrate, containing from 15 to 30 per cent. of the salt.* The term "*ohm*," on the other hand, is applied to designate the unit of measure of the "*resistance*" which any given electric circuit or part thereof offers to the passage of a current of electricity. Not only do the lines of force emitted by a current, and constituting the magnetic whirl surrounding every wire carrying a current, meet with a certain resistance in their passage through different media, as we have seen, but the current itself in passing through a circuit, no matter of what the latter may be composed, meets with a certain amount of obstruction or "*resistance*," so that by the insertion of a longer or shorter piece of wire, or of a longer or shorter column of liquid into the circuit, or of a wire of a greater or less diameter, a current can be diminished or increased in strength. Any number of amperes can be sent through any body, provided we have a sufficiently powerful generator or electromotive force to, as it were, pump or force the current through the resistance offered by the body, and provided further that the body is not fused or other-

* The usual strength of the currents used in telegraphing, over main lines, for example, is only from five to ten thousandths of an ampere, or five to ten milli-amperes, the prefix *milli*, indicating that the standard commercial unit, the ampere, has been divided by one thousand.

wise destroyed by the current before it has reached the required strength. The "*Ohm*," or the legal unit of this resistance, as settled by the International Electrical Congress, at their meeting held at Paris in 1884, is that resistance which is offered by a column of pure mercury 106 centimetres long, and 1 square millimetre in cross sectional area, at a temperature of 0° C. Previous to 1884 the unit of resistance used most extensively in Great Britain and elsewhere was the British Association, or "B. A." unit. The two units bear the following relationship:

1 legal ohm = 1.0112 B. A. units.
1 B. A. unit = 0.9889 legal ohm.

Since, as we have already shown, the strength or volume of a current is a function of the relationship of the electro-motive force and the resistance of the circuit through which it passes, then we should naturally surmise the existence of a law establishing the character of this relationship. Such a law was deduced by Dr. Ohm in 1827, and it has since been verified. This is now known as "*Ohm's Law*," and it may be briefly stated as follows: *The number of ampères of current flowing through any circuit is equal to the number of volts of electro-motive force divided by the number of ohms of resistance in the entire circuit.* Or, algebraically expressed:

$$\text{Current} = \frac{\text{Electro-motive force (in Volts)}}{\text{Resistance (in Ohms).}}$$

Or,

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

It must be borne in mind that the resistance here referred to is the whole resistance of the entire circuit, *i. e.*, the resistance not only of the circuit external to the source of supply, or generator, but also of the source of the current, or generator itself. For instance, if a number of cells of a battery are used, and the circuit be made up of a number of different parts through all of which the current must flow, we have to take into account not only the combined electro-motive forces of the cells, but the combined resistance of all the parts of the circuit, both within the cells and without. That is, the current may flow from the zinc plate of the first cell, through the liquid to the copper (or carbon) plate, then through a connecting wire or screw to the next cell, through its liquid, through the other connecting wires and liquids of the remainder of the cells, then through a wire to a Galvanometer, for instance, then through the wire coils of the Galvanometer, then perhaps through the whole or a part of the tissues of a human being, and finally through a return wire to the zinc pole of the first battery. In this case there are a number of separate electro-motive forces, all tending to produce a flow, and a number of different resistances, each impeding the flow and adding to the total resistance. If in such a case we knew the separate values of all the different electro-motive forces, and all the different resistances, we could calculate what the current would be, since it would have the value—

$$C = \frac{E' + E'' + E''' + \ldots\ldots\ldots}{R' + R'' + R''' + \ldots\ldots\ldots}$$

$$\text{Or, } C. = \frac{\text{Total Electro-motive Force.}}{\text{Total Resistance.}}$$

Where E represents the electro-motive force of each of the cells, and R the resistance of each portion of the circuit. Without a thorough comprehension of this law, which forms the basis of the whole science of electricity, it is impossible to deal intelligently with the science. Once having a thorough and clear conception of it, however, we are enabled to explain all of the varied phenomena. Knowing any two of the factors in the equation representing Ohm's law,

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

that is, knowing the resistance and the electro-motive force, we may, by calculation, determine the third factor, or the current; or knowing the current and the resistance in any given case, we may, by calculation, determine the electro-motive force; or knowing the electro-motive force, we may, by calculation, determine the resistance; since the *current* equals the electro-motive force divided by the resistance,

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

while the *electro-motive force* equals the current multiplied by the resistence ($E = C \times R$), and the *resistance* equals the electro-motive force divided by the current,

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

The So-Called Varieties of Electricity differ from each other only by reason of the preponderance of one or the other of these two qualities of pressure and volume. All the different so-called varieties will produce the same effects under similar conditions and relationship of resistance and pressure. If properly insulated, so-called static electricity, for instance, will flow and produce a current which will magnetize iron; and if it has sufficient volume it will decompose a liquid or heat a wire. If two static machines be placed upon opposite sides of a room, with their respective poles connected together by means of well insulated wires, and one machine be revolved by some power, the machine on the opposite side of the room will immediately begin to revolve, just as in the case of the transmission of power by means of two dynamo-electric machines, the one acting as generator and the other as a motor. The current here flows from one machine to the other. The current from an induction coil is also in every respect similar to a Galvanic current, except that it is intermittent and its direction constantly reversed, now flowing in one direction and then in the opposite direction. If, however, the current be "*commutated*" and caused to flow always in one particular direction, it is capable of producing the same chemical decompositions and magnetic effects that are produced by a Galvanic current. It has the same two qualities of pressure and volume, and the volume is a function of the relationship of electro-motive force and resistance, just as in the case of the Galvanic current. Hence it should be apparent that the effects produced by a Faradic battery, which is nothing but an induction coil, will depend entirely upon the volume or strength of current employed, which is likewise subject to Ohm's law, $C=\frac{E}{R}$—. Hence the strength of any Faradic current employed for medical purposes will depend solely upon the electro-motive force generated by the Faradic battery employed, divided by the total resistence of the circuit through which the coil is operating. This resistance will be made up of the internal resistance of the coils of wire of which the Faradic battery is composed, the resistance of the connecting wires, and also the resistance of the subject or of the tissues through which the physician may be passing the current. There is nothing mysterious about it. There is nothing that cannot be dealt with mathematically. Hence all the confusion of ideas and contradictory conceptions which prevail in the minds of most electro-therapeutists regarding the character of the current from different Faradic batteries and from coils composed of different sizes of wire, is all unnecessary. Here, as with the straight Galvanic current, it is purely a question of the strength or volume of current employed, and this is measurable in terms of the same unit which we employ with the Galvanic current, namely, the milli-ampere. With these principles in mind it will be seen that it does not necessarily follow that a coarse wire coil will give us the greatest strength or volume of current through all resistances.* It is customary, however, for the electro-therapeutist to make the mistake of always looking to the coarse wire coil for a great volume of current. The conditions of the relationship of resistance to the electromotive force may frequently cause us to obtain a current of greater volume from a fine wire coil than could be derived from the coarse wire coil when operating through the same resistance, and *vice versa.* The electro-motive force or pressure of the current derived from an induction coil or Faradic battery is principally dependent upon two things:

1. The strength or volume of the current flowing through the primary coil, any variation of which will cause a corresponding variation in the electromotive force of the current generated in the secondary coil.

2. The number of turns or convolutions of wire composing the secondary coil—*no matter what the*

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* Any more than it necessarily follows that a Galvanic battery arranged for "quantity" will always give the greatest strength or volume of current, irrespective of the resistance of the circuit through which it has to circulate.

size of the wire may be, an increased number of turns increasing the electro-motive force generated in the secondary coil. Of course, in order to get a great number of turns of wire in a given space, fine wire must be used, but the *size* of the wire has nothing to do with the character of the current generated. The fine wire secondary coil, while it will give a much higher electro-motive force, will also have a much higher internal resistance, and the strength or volume of current it will cause to flow will depend entirely upon the relationship of this electro-motive force to the total resistance of the entire circuit, *i. e.*, the internal resistance of the coil and the resistance of the parts or tissues through which the current is flowing. How absurd it is, then, for the physician to undertake to say that a current of great volume has been used simply because the large wire coil was employed. The failure to comprehend the nature of the problem involved here has given rise to many contradictory reports as to the comparative therapeutic effects of the coarse and fine wire secondary coils of a Faradic battery. For instance, Dr. G. Betton Massey, whom we all know well, writing to me under date of April 19th, 1890, says: "In the physics of the subject, I trust you will throw some light on the coarse wire nonsense in our induction currents as produced in the batteries we use. Although I am a disbeliever in a secondary coarse wire, and in my book speak slightingly of the primary induction current, I have recently noted undoubted evidence of high muscle-contracting power with the latter current, when the resistence of the circuit was minimized by very large poles." Could there be better proof of the truth of the principles just stated, or a better example of the prevailing chaotic and contradictory notions concerning this subject? Of course Dr. Massey noted better muscle-contracting power from the coarse wire coil in this particular instance! Why? Simply because the external resistance was low, as he states, and therefore he could get a great volume of current with a low electro-motive force such as is generated by the coil of fewer turns or "large wire coil." When we approach or withdraw the secondary coil to or away from the primary one, we respectively increase or decrease the electromotive force of the current generated in the secondary coil, by doing what is *equivalent* to adding to or taking away from the number of turns of wire composing the secondary coil. What we really do, however, is to place more or less turns of wire within the "*field of force*" of the primary coil, the internal resistance of the Faradic battery remaining the same all the while.

To sum up then, the whole question is purely one of *strength* of current, which must be *measured* in order to have any definite idea concerning its value, and thus be able to reproduce the same conditions a second time. It is to be regretted that we have never heretofore had an instrument for measuring the Faradic current. In the present work, however, the author will have the pleasure of presenting to the profession for the first time such an instrument, which has been christened the "*Faradometer*." This instrument will be illustrated and described later on.

THE QUANTITY OF ELECTRICITY which will flow by a given point or into a given body in any given time, will naturally depend upon the *volume* or *strength* of the current flowing, just as in the case of a stream of water flowing into a reservoir, where the quantity of water emptied into the reservoir in any given time depends entirely upon the volume or size of the flowing stream. Hence the *quantity* of electricity which flows through or into a body is equivalent to the product of the *volume* or *strength* of current (number of amperes) multiplied into the *time* the current is flowing. There is then a distinction between the *quantity* of electricity used and the *volume* or *strength* of current employed.

THE COULOMB is the established unit of measurement of the *quantity* of current, and its standard value is equivalent to that quantity of electricity which will flow through or into a body when one ampere of strength or volume flows for one second of time. A two ampere current flowing through or into a body for one second of time, or, on the other hand, a one ampere current flowing for two seconds, would represent a *quantity* of current equal to two *coulombs*. The physician who wishes to use electricity as a therapeutic agent with precision, and who desires to make and record accurate observations and thus secure uniform results, will have as much occasion to use this unit of quantity as he will have to use the unit of strength of current, for the one is of but little value without the other.

Electrical Units of Measurement are no simple fiction of the imagination. They bear a fixed and determined value and relation to the units of measurement of all other forms of energy, such as heat, light and dynamic force, and are convertable one into the other.

The principle of the correlation and conservation of energy, announced for the first time by Helmholtz, controls all problems in the measurement of force, and plays an important part in the application of the system of absolute units established by the British Association, and to the consideration of which the Congress, at the recent electrical exhibition in Paris, devoted much attention, with the object of establishing the system on an International basis. The term "*energy*" is applicable to all physical manifestations—mechanical work, the production of heat, light, etc Conservation results from the important fact that energy expended is always to be re-found integrally in some other expression of work—calories, chemical action, and so forth. It is evident, then, that the measure of the various forms of energy ought to be based upon a system of units intimately dependent one on the other and convertible one into the other, but the establishment of such a system is the work of time; several centuries, for instance, were required to create such a revolution as would sweep away existing prejudice and permit of the establishment and logical classification for the first time of a series of geometrical units for the measurement of space and weight.

Nearly a century ago, a National convention in France marked a great era in progress by the creation of the metric system, which takes as a basis of measures of length, area, volume, weight and mass, the metre, which is equal to the forty-millionth part of the length of the terrestrial meridian. This was the first step in the direction of establishing a universal and inter-convertable system of absolute units. The next step was taken by the British Association when it based the system of electrical measurements on the units of length, mass, and time, adopting for each the *centimetre*, the *gramme*, and the *second*, thus forming what is universally known as the centimetre, gramme, second, or C. G. S. system of units.

This C. G. S. unit of force is *that force which acting on a gramme of matter for a second, generates a velocity of one centimetre a second.* This unit is named the *Dyne*, and is equivalent to the $\frac{1}{980}$ of the weight of a gramme of matter at any part of the earth's surface, or, in other words, 980 *dynes* is about equal to the weight of one gramme of matter. This is then the C. G. S. unit of *force*. It was necessary to establish another fundamental unit to represent the *energy* or *work done* by any *force*. The C. G. S. unit of *work* or *energy* represents the work done in exerting a force of one *dyne* over the distance of a centimetre. This unit with the above value has been named the *Erg*. These two fundamental C. G. S. units of *force* and *energy*, then, constitute the foundation for all electrical units and measurements, and we shall now trace their relationship to the units of all other kinds of energy, whether manifested in the form of mechanical work, heat or otherwise, and show how they are convertible one into the other. The most generally employed expression of mechanical power, for instance, is the *horse-power*. It was introduced by that great thermo-dynamic engineer, Watt, and is equal to 33,000 foot-pounds per minute, which is equivalent to 76 kilo-grammetres, since the foot pound is about one-seventh of a kilo-grammetre. In France the horse-power is called the "*cheval vapeur*," and is equivalent to 75 kilogrammetres. Now, the kilo-grammetre, by the C. G. S. system is equal to 98,100,000 ergs, and the "*cheval vapeur*" is, therefore, equal to 7,357,500,-000 ergs. To avoid the use of numbers altogether too large to be convenient, such as the *absolute* C. G. S. units involve, the Congress adopted a series of *commercial* units, consisting of the *Volt*, the *Ampere* and the *Ohm*. The *volt* is equal to one hundred millions of absolute C. G. S. units of electromotive force, or ten to the eighth power (expressed 10^8); the *ohm* is equal to one thousand millions of absolute C. G. S. units, or ten to the ninth power (expressed 10^9). By this time the reader should have a very clear idea of the definite and immutable character of these electrical units, and of their fixed relations to the units employed in dealing with all other forms of energy; and it should be impossible for him to commit the error embodied in the following statement made by a recent author of considerable note, whose work is before us, and from which we quote: "*A milli-ampere is resistance offered by a human body to a current of electricity which is generated by the Daniell's element.*" The author in question might with equal correctness have said that a gallon is equal to a gas-pipe, or a mule's hoof to a boy's aching stomach.

Electric power is the product of the pressure or electro-motive force of a current in *volts* multiplied into the strength or volume expressed in *amperes*.

The Watt is the name of the unit employed to express this product of the *volt-ampere*, and it is equivalent to one seven hundred and forty-sixth ($\frac{1}{746}$) of a horse-power; that is to say, seven hundred and forty-six (746) watts equal one horse-power; hence the volts of pressure multiplied by the amperes of strength of any current, the product being divided by

746, will give the power of the current in "*horse-power.*" Whence the formula :—

$$H.\ P. = \frac{\text{Volt} \times \text{Amperes}}{746} \text{ or } \frac{E \times C}{746} = H.\ P.$$

With this further information properly assimilated, the reader should be able to appreciate the fallacious character of the statement contained in a paper recently read before the American Medical Association, which was to the effect that the author of the paper had frequently used a TEN AMPERE (not *milli*-ampere) current in the treatment of uterine fibroids, the current being passed through the abdominal walls to an electrode placed in the tumor per vagina. The very lowest possible resistance offered by the tissues of the body in a case of this kind, no matter how large the abdominal electrode, would at least be not less than sixty ohms. Now by Ohm's law ($E = C \times R$) we may know that the electro-motive force which must of necessity have been employed in order to force this ten ampere current through the sixty ohms of resistance offered by these tissues, was ten multiplied by sixty, which gives six hundred volts. And now, since the current in amperes multiplied by the electro-motive force in volts gives us the number of watts of power employed, we have ten multiplied by six hundred as the number of watts. This product, which equals six thousand, when divided by the constant 746, gives us the horse-power of energy which must have been expended for five minutes of time upon any such patient. Now just for one moment imagine the whole of EIGHT HORSE-POWER of *any* form of energy—whether it be in the nature of the mechanical power of a shaking machine, heat, chemical action, or electricity, being expended upon a human being and that person still living! We do not recite this circumstance to the disparagement of the writer of the paper in question, for we are well acquainted with him, and know him to be thoroughly conscientious and honest, but rather for the purpose of giving a single instance in illustration of the practical value to an electrologist of a thorough knowledge of the science of electricity, and the necessity for the exercise of great care in the selection and use of electrical measuring instruments.

Having now discussed in a general manner the nature of that condition known as electrification, and the laws governing the circulation of electrical currents, we shall immediately proceed to describe the *technique* and apparatus necessary for the scientific application of this form of energy to the medical and surgical uses of the physician and surgeon, leaving the many and varied electrical and electro-magnetic laws and phenomena with which we shall be obliged to come in contact, for consideration in connection with the practical application of the knowledge, feeling that in this way these laws and phenomena will be the better impressed upon the mind of the reader.

CHAPTER III.

THE APPLICATION OF ELECTRICITY IN MEDICINE AND SURGERY.

THE NECESSARY PARAPHERNALIA for the scientific application of electricity in medicine and surgery should comprise:

1. A generator or source of supply from which to derive the "direct," or Galvanic current.

2. *A current controller of proper design and construction for regulating the strength of the current.*

3. A milli-ammeter of proper design and construction for accurately measuring the STRENGTH *or* VOLUME *of the Galvanic current.*

4. A coulombmeter for measuring the QUANTITY *of the direct or Galvanic current employed in any case.*

5. A volt-meter for occasionally determining the total electro-motive force of the generator or source of supply, or of individual cells of a battery, and for use in measuring differences of potential of various parts of the circuit, as a means of checking up other measurements and measuring instruments.

6. A direct reading ohm-meter, or a box of standard resistances, for measuring the resistance of different parts of the body at different times, and for making tests of the resistance of various other parts of the circuit.

7. *An adjustable rheotome for interrupting either the Galvanic or Faradic currents any required number of times per minute.*

8. *An induction coil of suitable range for generating alternating currents of varying electro-motive forces.*

9. *A Faradometer for measuring the strength of the Faradic currents being employed at any time or in any given case.*

10. *An electro-static induction machine for generating currents of small strength but extremely high electro-motive forces.*

11. *Various other accessories, such as switches, pole-changer, connecting-cords or rheophores, suitable variety of electrodes, electrode-handles, etc.*

The contention is not made that all of these things are absolutely necessary to the simple use of electricity. One or all may be dispensed with, just as many practitioners entirely neglect the use of electricity in medicine. But what we do contend is, that the degree of success which any practitioner will meet with in the practice of medicine, will largely depend upon the extent to which he utilizes this most important form of energy called electricity, and that its scientific administration with a view to advancement and the establishment of it upon an exact rather than an empirical basis, demands the use of all of this apparatus, just as much as does the study of bacteriology require the use of at least a good microscope.

THE GENERATORS OR SOURCES OF ELECTRICAL

SUPPLY from which the medical practitioner may derive electricity for medical and surgical uses are:

a. Central Power Stations.

b. Individual Dynamo-Electric Generators.

c. Galvanic Cells.

(*a*) CENTRAL POWER STATIONS OR ELECTRIC LIGHT MAINS, have recently been resorted to as a source of such supply. Although among the first, if not *the* first, to employ currents from such stations, the author unhesitatingly pronounces in favor of the primary battery for general electro-therapeutic work, and recommends the use of currents from electric mains only for the operation of electric motors and the charging of so-called storage batteries to be used in heating cautery electrodes, maintaining electric lamps, and operating electric motors outside of the office, and inside the office in case of a "shut-down" at the central station.

Unless specially designed for the purpose, and provided with an "armature" (the revolving coil of a generator) having a great number of sections and run at a positively uniform speed, the ordinary dynamo-electric generator such as we find in these stations does not furnish an electric current suitable for general therapeutic purposes. The current is physically the same as that derived from a Galvanic cell, and will produce the same chemical and physiological effects, but it is too fluctuating for use as a therapeutic agent. It is impossible, without producing unbearable pain, to use the same strength of current in any given case that could be given were a battery current employed. Its use involves too many chances for painful and dangerous shocks.

The use of storage or secondary batteries for general electro-therapeutic work is precluded by reason of the high electro-motive force which is generally required for therapeutic purposes. The number of ordinary storage cells which would be required to establish this necessary electro-motive force would be so great as to make a battery of enormous weight and great cost. Storage cells, again, are apt to give a great amount of trouble, require very careful handling, and are subject to instantaneous discharges and even complete destruction through some slight inadvertency on the part of the operator. Hence their use should be resorted to only for those purposes which occasionally demand a very strong current, such as Galvano-cautery, etc.

(*b*) INDIVIDUAL DYNAMO-ELECTRIC GENERATORS with a great number of armature sections have been designed, and in a few instances employed by physicians, to give currents for general therapeutic, illuminating and cautery purposes. The first machine of this kind was designed and used by the author in 1887. The machine was made according to the author's design by the Excelsior Electric Light Company of New York, and is capable of giving either of two currents upon a simple changing of some plugs upon the top of the machine; one of the two currents has an electro-motive force of four volts and a possible strength of forty amperes, and is suitable for all cautery and illuminating purposes; while the other current has an electro-motive force of forty volts and a possible strength of four amperes, and is suitable for most therapeutic purposes. Machines similar to this are now regularly manufactured and upon the market as a staple article. The best machine of this kind is illustrated in Fig. 10.

This machine generates two distinct currents at the same time, the armature being a compound one with two separate and distinct windings, each of which are respectively connected with two separate and distinct commutators, so that both currents may be utilized for different kinds of work at the same time, or either one separately. One of these currents is identical with that generated by a cautery battery of cells having elements with large surface, while the other current is similar to that generated by a large number of cells arranged in "series;" the two are designated respectively the "*cautery*" and the "*electrolytic*" current. The maximum electro-motive force of the former is five volts, with a possible strength of sixty amperes; while the maximum electro-motive force of the latter is two hundred volts, with a possible current of one ampere. Either current may be varied from zero to full power by a simple rotation of the "*rocker-arm*" or "*brush-holder*" of the corresponding side. An automatic safety device in the nature of a fuse is supposed to prevent the current

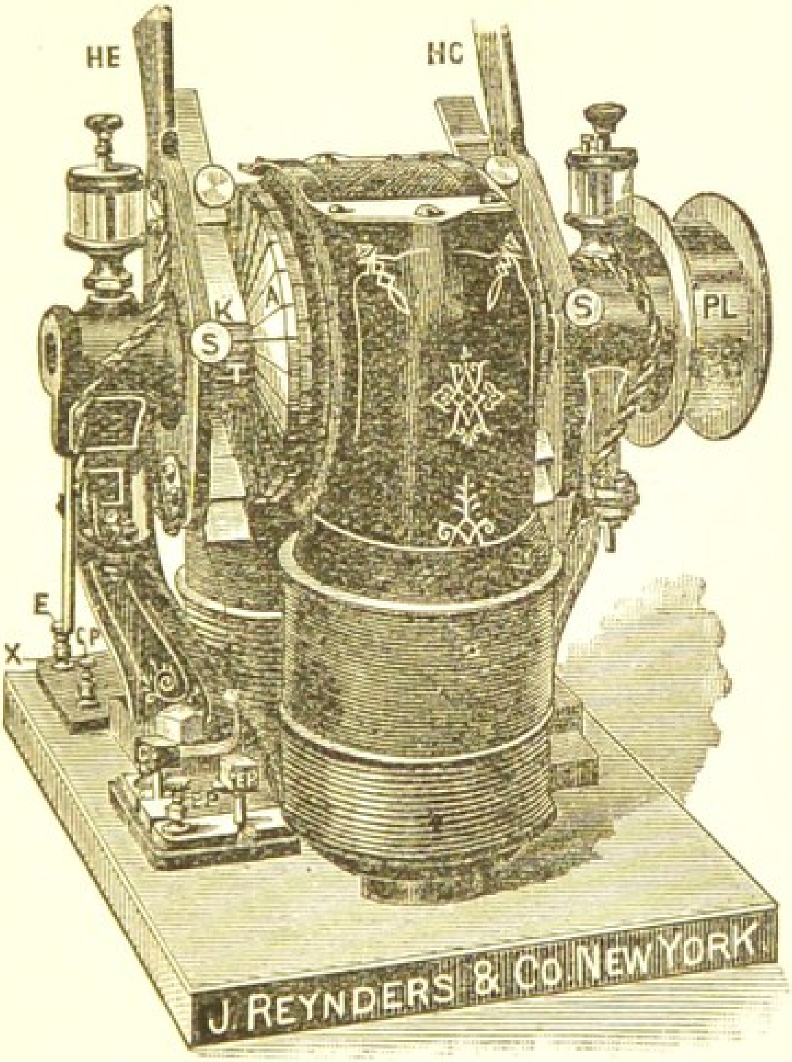

FIG. 10.—THE MEDICAL DYNAMO.

H E—Handles for rotating brushes on the electrolytic side.
H C—Handles for rotating brushes on the cautery side.
S S—Thumb screws for setting brushes.
A—Armature.
K K—Brushes.
C P—Positive post of cautery current.
C—Negative post of cautery current.
T—Commutator.
X—Safety fuse.
E P—Positive post of electrolytic side.
E—Negative post of electrolytic side.
C and *E P*—Plugs for increasing or diminishing the current.
P L—Driving pulley.

from reaching a strength that would be calculated to harm a patient, destroy a cautery electrode, or injure the machine itself. This machine will generate a current that is steady and reliable, and that is equal to that produced by the largest cautery battery made for office work, while at the same time producing another current with sufficient electro-motive force to operate a 16-candle power incandescent lamp, or do any work that can be accomplished by a battery of 150 Lelanché cells. This machine should be run at a uniform speed of 1,800 revolutions per minute, by either an electric motor, a gas engine, a water motor, or a steam engine of one-horse power, preferably the former, if electric mains are at hand. If one has a large special practice, and is *permanently* located near electric mains that are kept energized the whole twenty-four hours, and if the care and manipulation of electric machinery is quite well understood by the would-be user, then the medical dynamo may be recommended as a very desirable source of electric supply. Our advice to the general practitioner, however, is to let the medical dynamo religiously alone.

(*c*) GALVANIC CELLS OR BATTERIES are pieces of apparatus or devices for converting *chemical* energy into *electrical* energy. The production of electrical energy is, strictly speaking, only the conversion of one form of energy into another form of energy, or one mode of motion into another mode of motion. All forms of apparatus which produce electrical energy at the expense of chemical action, are called "Galvanic Cells," and an aggregation of such cells is spoken of as a "*battery*" of cells or as "*batteries.*" While there are many varieties of these cells upon the market, there are, nevertheless, but few which may be said to meet the requirements of the medical man. It is a chimerical fancy to suppose that any *one* form or kind of battery will meet all of these requirements. One might with equal reason and success seek in one form of apparatus a source of electrical supply which would be equally suited to the varied purposes of *electro-chemical deposition*, *gilding*, *silvering*, the production of *arc* and *incandescent lights*, the operation of *converters* or *induction coils*, the discharge of *torpedoes*, the propulsion of *aëreal ships*, and the operation of *telegraph lines*, *bells* and *telephones;* each of which requires a special form or kind of generator adapted to meet the peculiar exigencies of the work to be performed. Just as in the case of these several industries, the medical man will in his office require one form of battery for charging "*secondary*" or storage batteries, another form for *cautery*, motive power, and illuminating purposes, and another for neurological and gynæcological work; and different forms of all of these for work outside of the office. The writer has had a wide experience with many hundreds of cells, involving almost all types, and covering a period of something like fifteen years. In addition to this practical experience, the author has recently examined and made careful comparative electrical tests of all the latest leading forms of such types of cells as would be likely to meet the requirements of the medical profession, with the object of being able to give a definite and reliable opinion in the present work.

Galvanic cells may be divided into two principal classes: *Open Circuit Cells* and *Closed Circuit Cells.* Those which come under the first class are the only ones which are suitable for therapeutic purposes. What is commercially known as the *Leclanché cell* is the typical representative of this class, and of the many forms of it which we find upon the market, the two best are the "*Gonda*" and the "*Axo*" cells manufactured by the "Leclanché Battery Co.," of New York (see Figs. 11 and 12).

Fig. 11.—"Gonda" Battery Complete.

Fig. 12.—"Axo" Battery Complete.

The Theoretical Conditions of a Perfect Battery are:

(1) *A high electro-motive force.*

(2) *A low and constant internal resistance.*

(3) *A constant electro-motive force irrespective of the current produced by the cell.*

(4) *A consumption of inexpensive materials.*

(5) *A lack of cousumption of all material when no current is being produced, that is, when the circuit is not closed.*

(6) *A ready means of occasionally examining its condition and working, and of adding fresh materials when required.*

It should always be borne in mind—

That the electro-motive force of a Galvanic Cell is independent of its *size*, a cell no larger than a thimble giving as high an electro-motive force as one the size of a barrel.

That the character of the elements employed dedermines the electro-motive force of the cell, all cells having similar elements giving *practically* the same electro-motive force.

That one cell will give practically the same strength of current on a short-circuit as one hundred similar cells arranged in series.

That no greater strength of current can be gotten out of one hundred cells arranged in series than one cell will give on a short-circuit.

That one hundred cells arranged in series will, however, force the same strength of current through one hundred ohms of external resistance that one cell will create through one ohm.

That the strength of current which any cell will give is dependent on its internal resistance, which latter is entirely governed by the extent of surface of the elements, their proximity to each other, and the character of the solution employed, an acid solution offering less resistance than an alkaline one.

The Leclanché cell proper is composed of a glass jar, a cylindrical rod of zinc as a positive element, and a porous cell containing about equal quantities of manganese dioxide and gas carbon as a negative element. The glass jar is half-filled with a saturated aqueous solution of ammonium chloride, or *sal ammoniac.* There is no chemical action till the circuit is closed. Its electro-motive force varies from 1.2 to 1.5 volts, and the internal resistance varies from .5 to 5 ohms. It contains no acids and no poisonous substances, gives off no acid vapors and no odor; the materials used are cheap and easily replaced, and resist the most intense cold; so that, as a type, it more nearly fulfills the above conditions than any other form of cell.

The "*Axo*" cell is the best pattern of this regular standard type. A modification of the Leclanché, has recently been devised, in which the porous cell is replaced by a conglomerate block composed of a mixture of forty parts of manganese dioxide, fifty-five of carbon, and five of gum-lac, the whole being subjected to a pressure of three hundred atmospheres at 100° C. The "*Gonda*" cell is the best and latest form of this modified Leclanché cell. This cell has an electro-motive force of 1.5 volts, which is unusually high, with as low an internal resistance as any other cell of its kind. It "*polarizes*," that is, its internal resistance increases very slowly under action, and it "*depolarizes*," that is, resumes its original resistance, very rapidly under rest. The positive pole outside of the battery, it must be borne in mind, comes from the negative or manganese and carbon element, while the negative pole comes from the positive or zinc element. These open circuit cells require but little attention, and one charge of the solution will last from six months to several years, according to the amount of work imposed upon them. Even with daily use upon a number of patients, the zinc element will last at least one year. The time will surely come, although it may not be for quite a while, when the manganese-carbon element must also be renewed. There has, however, more recently still been introduced a form of cell which does away with this porous cup of manganese and carbon, substituting a simple element of gas carbon having a very large surface. Such elements with proper care are practically everlasting. The very best pattern of this form of open circuit battery is represented by what is commercially known as the *Double Cylinder* "*Law*" battery manufactured by the Law Telephone Co., of New York, and shown in Fig. 13.

The negative element (positive pole) is formed of a double cylinder of gas carbon, which furnishes a

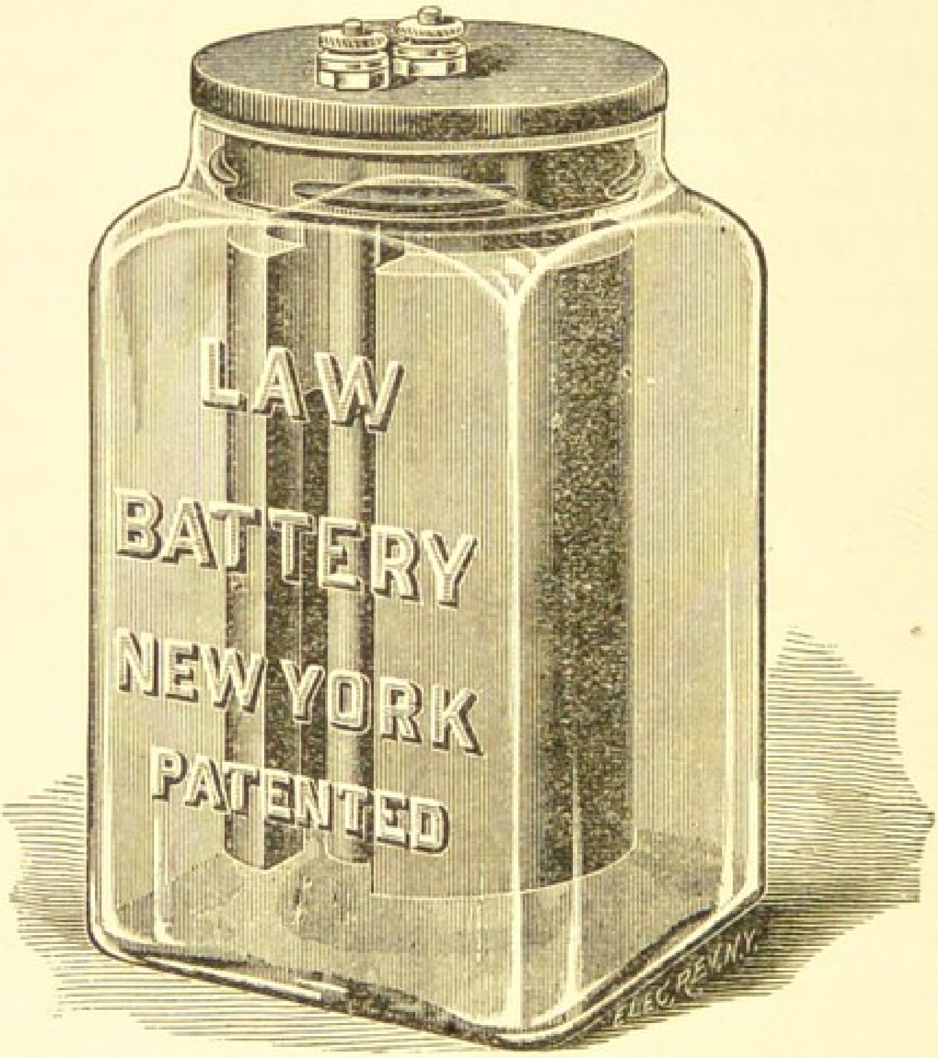

FIG. 13.—THE DOUBLE CYLINDER "LAW" BATTERY.

very large surface that reduces the internal resistance and enables a ready escape of the polarizing gases, thus requiring no depolarizing agent such as manganese. This negative element of the *Law Battery* is practically everlasting. In all porous-cup batteries which require a periodical renewal of the negative element, the first cost of the cell is insignificant as compared with the subsequent cost of these renewals. Both the carbon and zinc (negative and positive) elements of this battery are permanently attached to a composition cover closely resembling hard-rubber (see Fig. 14), which is so constructed that by a slight turn it locks down upon the jar tightly with an intervening soft rubber ring, thus effectually sealing the jar and preventing a rapid evaporation of the solution and a crawling or creeping out of the ammonia salt. The absence of such a device in all other forms of this type of battery constitutes a serious defect, and the effort to accomplish the same end by coating the top of the jar with a greasy substance like paraffin, is both ineffectual and dirty. The jar of this battery is more compact and contains more fluid for the cubic space occupied than that of any other. Both connections are alike, and of the most compact and best form. It is elegant in appearance, and its mechanical construction is of the highest order. Our own measurements show that the electro-motive force averages 1.35 volts, although the makers claim 1.5. The current which it will give upon a "*short-circuit*," that is, through an inappreciable external resistance, varies from 1 to 2½ amperes. Although the electro-motive force of this cell is slightly below that of the "*Gonda*," taking into consideration its compactness, its perfect mechanical construction, its air-tight seal, its cleanliness, its indestructible negative element, and the beauty and symmetry of its outline, we would recommend it above all others as the best form of stationary battery for medical purposes. In all open circuit batteries both elements remain in the solution all

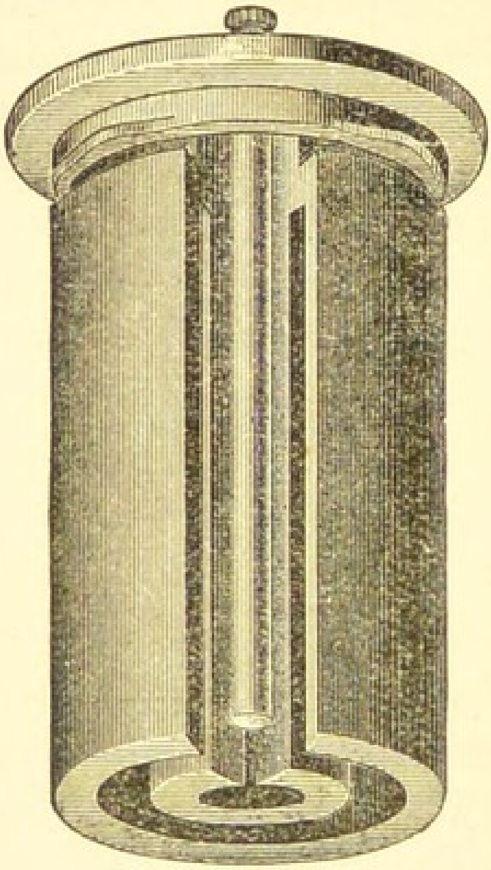

FIG. 14—COVER AND THE TWO ELEMENTS OF THE LAW BATTERY.

the time, and there is no consumption of any of the materials except when the circuit is closed and the current flowing, and even then the consumption of materials is strictly in proportion to the strength of the current being generated, or, in other words, inversely proportional to the resistance through which the batteries are working. This peculiar feature admits of the use of all of the cells or the full electromotive force of the battery at once, introducing a large artificial resistance to cut down the strength of the current; this resistance may then be gradually withdrawn until the required strength of current is attained. Such a variable artificial resistance for regulating the strength of the current is known as a current "*controller*."

THE CURRENT CONTROLLER is indispensable in all Galvanic work, and frequently very useful in Faradic work. Its office is to turn off and on the current, steadily and gradually, and thus prevent disagreeable and injurious shocks in all cases where these are to be avoided. It is nothing more nor less than a "*rheostat*" which interposes a certain initial artificial resistance, which may be very *steadily* and *gradually* withdrawn and reinserted under the manipulation of the operator. thus correspondingly increasing and decreasing the strength of the current, a graduation that is impossible with the old "*cell-selectors*," "*wire-coil rheostats*," and "*primitive water rheostats*" that it supplants. Its principal advantages over the old wire-coil rheostats, and cell-selectors are:

1. Its simplicity; avoiding all the complicated wiring incidental to the others.

2. Its greater certainty of preventing shocks.

3. Its distribution of the wear equally amongst all the cells of the battery, which is a most desirable feature.

4. Its saving of the necessary exhaustion of each cell as it is short-circuited by the selector-crank in turning on and off cells by means of the current-selector.

5. Its need of but two terminal wires, which renders it possible to connect a stationary battery with a movable table holding the apparatus.

The "Bailey Current Controller," Fig. 15, made by the Law Telephone Co. of New York, is probably the best controller at present upon the market, although Dr. G. Betton Massey, of Philadelphia, in his recent admirable work on "Electricity in the Diseases of Women," describes one of his own design, made by Otto Fleming of same place, which he claims is superior to it; and from his description we can certainly recognize several points of advantage. We only hope that the uncertain and perishable character of the pencil mark used as a resistance in the Massey controller, will not prove an offset to these advantages. The Bailey controller consists of four carbon plates which are mounted so as to be readily immersed in a jar of water by means of a rack and pinion. Two of these plates are connected together metallically to form a pair, and the pair is connected with one of the binding-posts of the apparatus. The remaining two plates are also connected together to form another pair, and these are again connected with the other binding-post. The two pairs of plates are insulated one from the other,

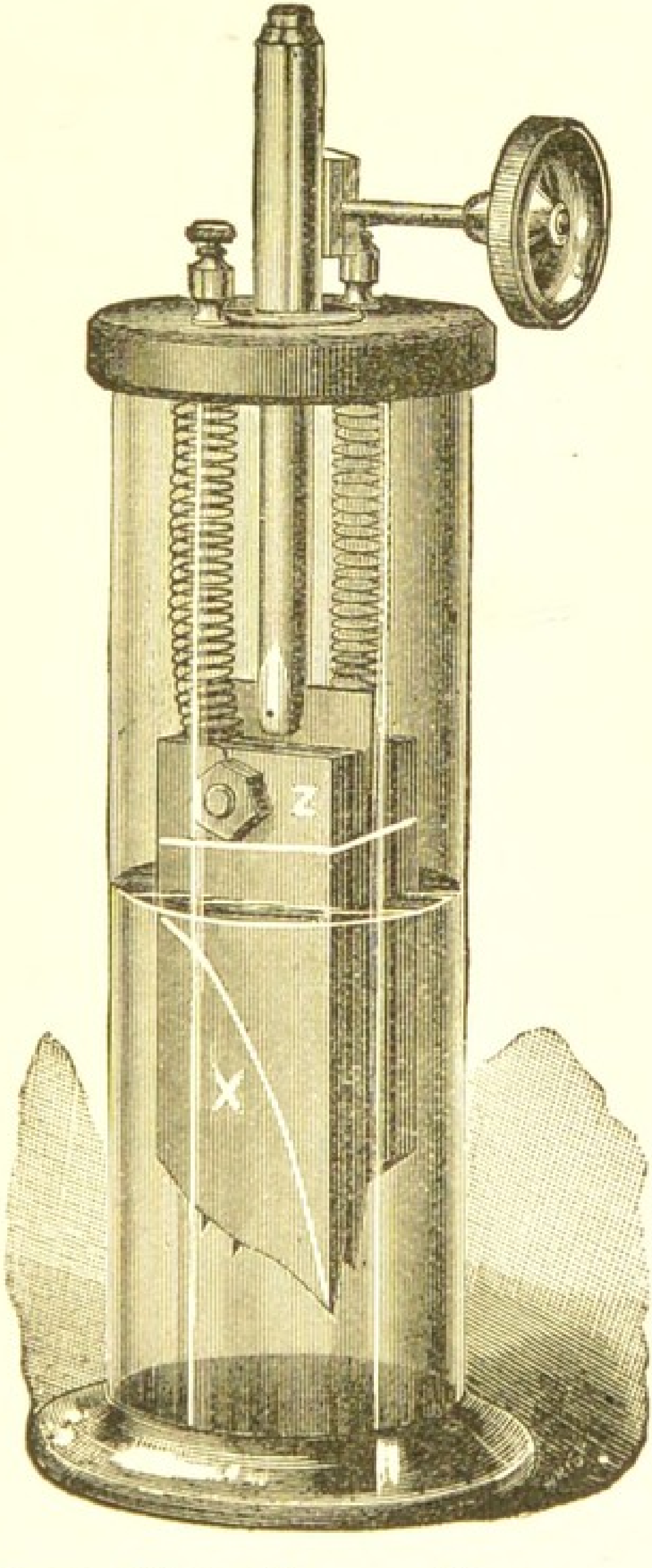

FIG. 15.—BAILEY CURRENT CONTROLLER.

and the current must pass from one pair of carbon plates to the other through the water. When entirely out of the water, no current is supposed to flow. Of course the resistance which the current meets with, in its passage from one pair of plates to the other, will depend upon the extent of surface of the plates brought in contact with the water, and this is varied by raising and lowering the carbon plates in the water. As found upon the market at the present time, this controller, however, possesses the following serious defects: The metallic connections within the jar soon corrode, thus creating a very high resistance, finally crumbling to pieces and breaking the connection entirely; by capillary attraction and the condensation of moisture, a film of water is soon formed upon the insulating strips between the pairs of carbon plates, which forms a conducting bridge for the continuous passage of the current even before the carbon plates touch the surface of the body of water, thus causing a disagreeable shock in delicate electrizations, and frequently even completely destroying the function of the controller; owing to an improper shape of the carbon plate, the gradations of the current's strength are not sufficiently gradual and regular; when the carbon plates are completely immersed in the water there still remains from ten to thirty ohms resistance in the circuit, which should be entirely removed. All but the last of these defects may be removed in the following manner: Unscrew the carbon plates from the suspending rod and rack, and after subjecting them to a dry heat equal to the temperature of melted paraffin, immerse the upper end of the carbon plates, connections and all, in the melted paraffin, down to a point indicated by the line Z in Fig. 15, keeping them in the hot paraffin for several minutes, then gradually allow the paraffin to cool and remove the plates. Before doing this, however, take the plates apart, and with a fine key-hole saw cut the lower ends in the manner indicated by the line X in Fig. 15, so that the corners formed by the opposite pairs of plates will form a paraboloid. Remove the sponge tips. Bore a fine hole in the lower end of each carbon plate, and insert therein a piece of the lead from a pencil, about one-half inch in length.

The plates, when viewed from the side, will now present the appearance shown in Fig. 16. When the plates are so treated, and made into this shape, the whole condition of affairs is changed, and the Bailey controller becomes a very valuable and sensitive piece of apparatus. The connections will not corrode, and when the plates are now slowly immersed, we not only very gradually increase the surface of the plate exposed to contact with the water, but we also gradually decrease the length of the path that the current has to travel in going from one pair of plates to the other, which, at the start, is from A to B, or from one pencil point to the other. It will be seen from the figure that this distance is very gradually decreased, as well as the exposed surface increased as the plates are immersed to a greater depth. With the Bailey controller as modified by the author, the current may be turned on *progressively* and *regularly*, without a jump

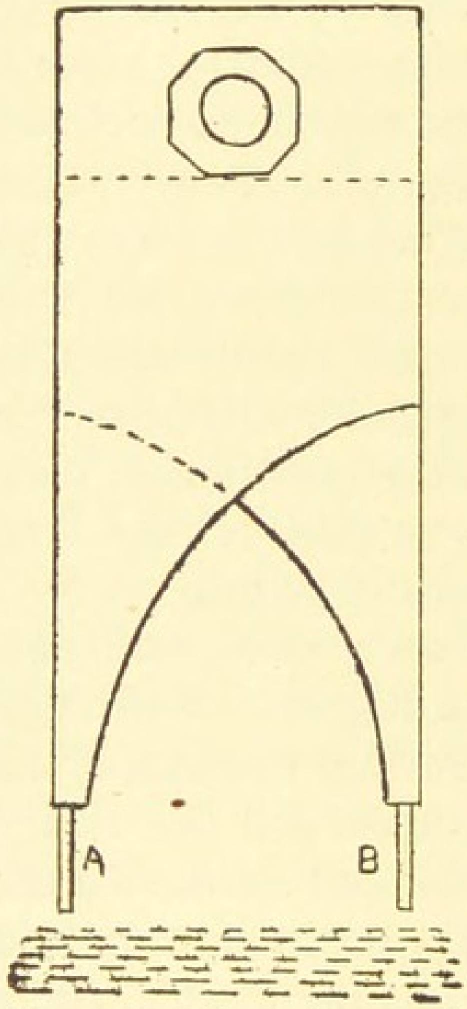

FIG. 16.—THE AUTHOR'S MODIFICATION OF THE BAILEY CONTROLLER.

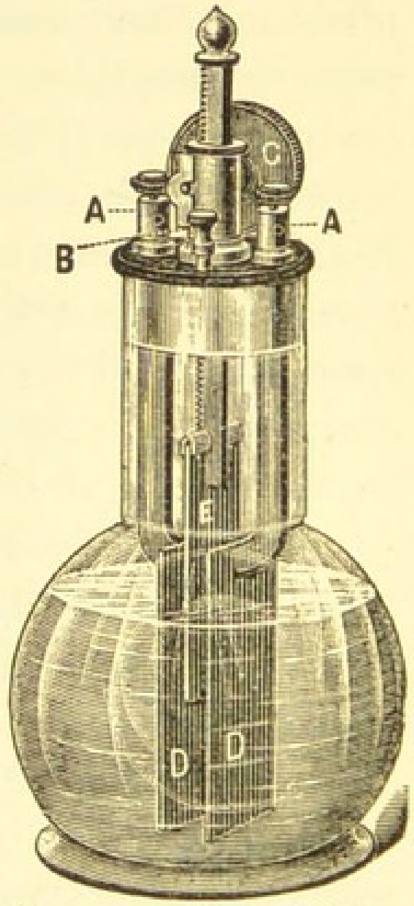

FIG. 17.—THE MCINTOSH CURRENT CONTROLLER.

or an oscillation, at the rate of only one one-hundredth of one milli-ampere for each increment of current strength. There then remains but one defect, which consists in the inability to finally remove all of the resistance without a sudden jump.

Another form of controller has been placed upon the market by the McIntosh Battery Co., of Chicago [see. Fig. 17], but we do not think well of it; besides, its cost is excessive. Between two small sheets of platinum (D, D) suspended in water, with suitable attachment (A) for one pole of the battery, is suspended a third piece of platinum (E) that can be lowered or elevated by means of a rack and pinion (B, C).

THE MILLI-AMMETER is the most important and delicate instrument that we have to deal with. A trained physicist, who is acquainted with all of the influencing conditions, can, in his laboratory, determine the strength of any electric current by means of an ordinary Galvanometer, because such a Galvanometer —of a particular shape and size, and with a definite magnetic needle, acted on by a definite controlling force produced, for instance, by the earth's magnetism, or by some fixed permanent magnet—has a perfectly definite law connecting the magnitude of the deflection with the strength of the current producing it. But such an instrument cannot be carried around everywhere, and everybody cannot use it. The scale is only divided into the degrees of a circle, whereas the strength of current is proportional to the tangent of the angle of deflection, so that in any case of measurement with such an instrument, the tangent of the angle of deflection must be sought for in a table of tangents, which necessitates a complicated calculation involving as factors the component of the earth's magnetism at the place, and the "*constant*" of the Galvanometer. To avoid the necessity of such a complicated process, and enable anybody to read directly from an instrument the strength of current flowing through it in terms of the unit of current strength (the ampere), ordinary Galvanometers have, for some time, been made, in which the ordinary degree divisions have been replaced by divisions the lengths of

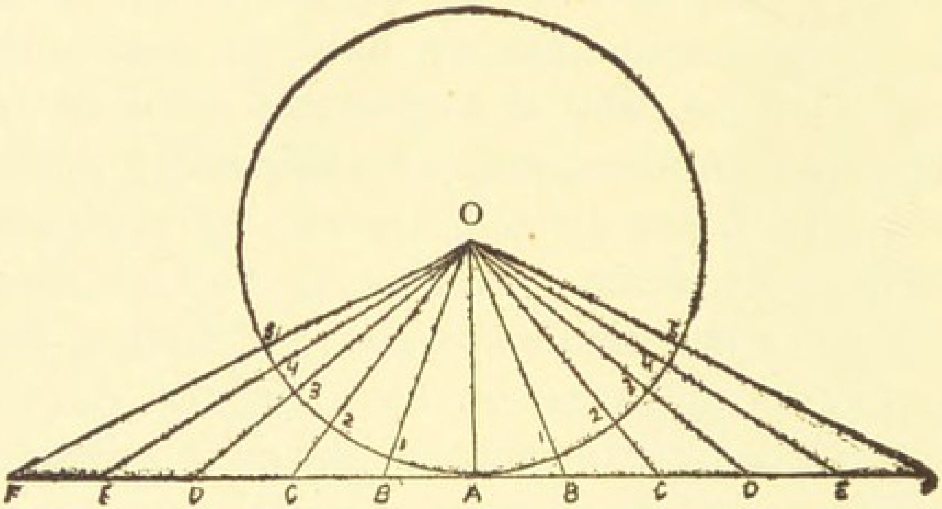

Fig. 18.

which become smaller and smaller as we depart from the zero or undeflected position of the needle, in such a way that the number of divisions in any arc is proportional to the tangent of the angle corresponding with that arc. The accompanying diagram (Fig. 18) will make this clear.

The lengths A B, B C, C D, etc., along the line A F, which is tangent to the circle at the point A, are all made equal to one another; hence, if from the centre (O) of the circle, straight lines, O A, O B, O C, etc., be drawn, cutting the circumference of the circle at the points A, 1, 2, 3, etc., the numbers 1, 2, 3, 4, etc., will be respectively proportional to the tangents of the angles A O 1, A O 2, A O 3, etc. The spaces between the lines drawn from the center of the circle (O) to the various points A, B, C, D, etc., on the line A F, are equi-distant, but at the points where they cut the circle at 1, 2, 3, etc., they rapidly approach each other as they are drawn further from the vertical line O A. Suppose now that we wind a Galvanometer with a coil of wire of such size or of such a number of turns that a current of ten milli-amperes will deflect the needle from its zero or resting point (A) to point 1 on the circle, then a current of twice this strength or twenty milli-amperes should deflect the needle to the point 2, because the line O C cuts the circle at this point, and C is the same distance from B that B is from A. In like manner, thirty milli-amperes would deflect the needle to 3, and forty to 4, etc. The limit of this proportionality in most instruments is reached at from 50° to 60°, and beyond this point the needle moves over such a small distance for large increments of current that measurements in this part of the scale are of but little value. This fact greatly limits the range of such instruments. This same supposed instrument may be rendered more sensitive by using a greater number of turns of a finer wire for the windings, so that only one milli-ampere will deflect the needle to the point 1 on the circle, when five milli-amperes will deflect the needle to the point 5, because the point F is just five times the distance from A that the point B is. In like manner the instrument may be made less sensitive

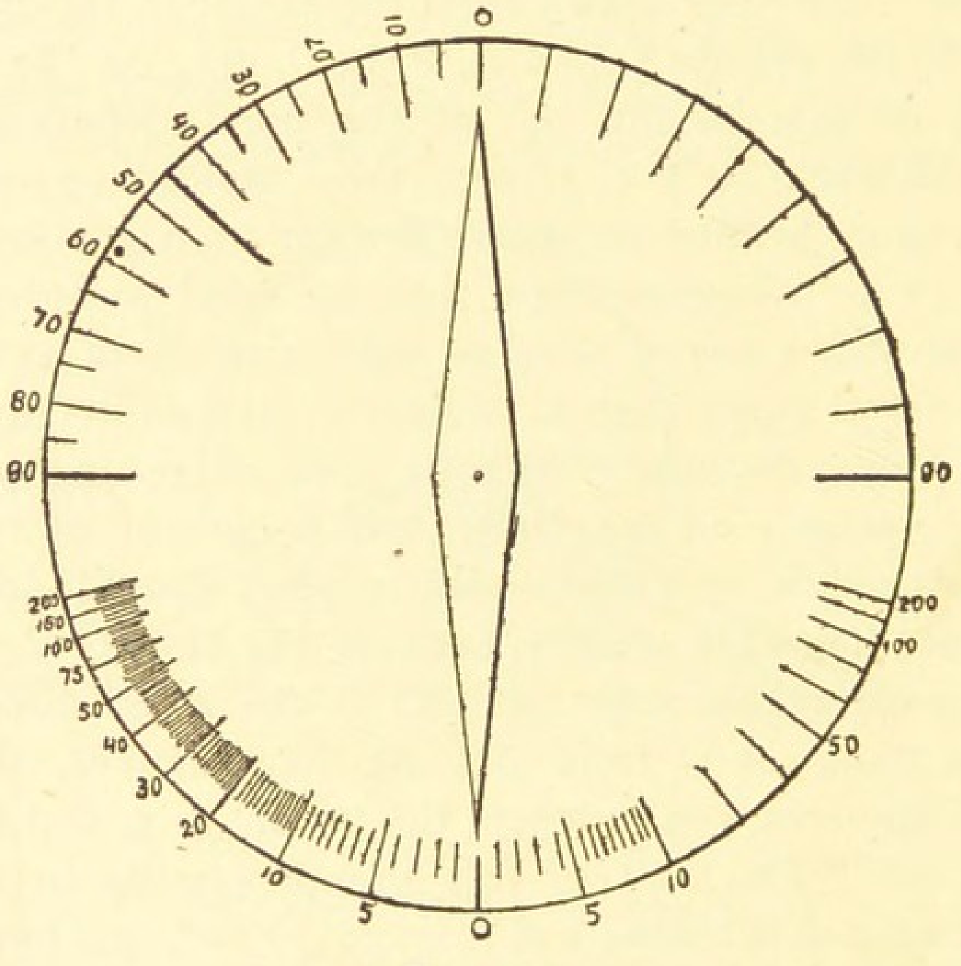

FIG. 19.

than in the first case by using fewer turns of a coarser wire than was first used, so that a current of one hundred milli-amperes will only cause a deflection of the needle to the point 1 on the circle, in which case a deflection of the needle to the point 5, will indicate five hundred milli-amperes or one-half an ampere. It will be observed that in all three of these cases the law of tangent proportionality remains the same, in each case a movement from A to 2 indicating twice as much current as the movement from A to 1, although in each case the actual amount of current causing this movement may differ, in the one case the strength of current being two, in the other twenty, and in the third case two hundred milli-amperes.

The difference between an ordinary Galvanometer whose scale or dial is divided into simple de-degrees, and one which has its scale or dial divided so as to read the current strength directly, is clearly shown in Fig. 19, where the dial in its upper half is divided into degrees, and in its lower half into milli-amperes. The principle that the angle of deflection does not increase proportionally to the strength of current, is illustrated by the fact that whilst a current of 30 milli-amperes deflects the needle to about 45°, a current of 150 milli-amperes is required to deflect the needle to 70°.

Such a direct reading instrument as we have just described, operating against the controlling influence of the earth's magnetism, upon the principle simply of an ordinary Galvanometer, is known as a "*calibrated*" Galvanometer. Such instruments have been made and placed upon the market by various instrument makers at home and abroad, notably, Gaiffe, Mc-Intosh, Waite and Bartlett, and called "*Direct Reading Ammeters*" and "*Direct Reading Milli-Ammeters.*"

As a matter of fact, however, such instruments are not, in the strict sense of the word, "*Direct Reading Ammeters.*" As we have already stated, the Galvanometer employs the earth's magnetism, as the controlling force against which the strength of any electric current is balanced, hence this force must be constant for all time and places, in order to have an instrument calibrated in one place and at one time, read correctly at all other places and at all other times. Now, as a matter of fact, the force of the earth's magnetism is not constant for all years, nor for all parts of the globe. The subjoined table will give an idea of its variations as regards both time and place:

	YEAR.		
PLACE.	1870.	1875.	1880.
Paris	1 94	1.96	1 98
London	1.78	1.80	1.82
Leipzig	1.86	1.88	1 90
Darmstadt	1.91	1 93	1.95
Edinburgh	1.62	1 64	1.66
Zurich	2.00	2.02	2 04
Dublin	1.67	1.69	1.71
Turin	2.07	2 09	2.11
Vienna	2.05	2.07	2 09
Königsberg	1.79	1 81	1.83

Since the angle of deflection produced by a given Galvanometer is evidently proportional to the directive or controlling influence of the magnetic force acting on the needle, it is obvious that the indication of any Galvanometer calibrated in London, for instance, would be excessive when used in Turin or Vienna, in the proportion of 1.82 to 2.11 and 2.09 respectively, or deficient when used in Edinburgh or Dublin. Hence correction must be made for different places and different times when using such instruments, and they cannot, therefore, be called *direct* reading instruments in the strict sense of the word. Again, the presence of any small amount of inductive material, such as iron, steel, or artificial magnets, in the neighborhood of such instruments, causes an error in their reading. It has, therefore, been found necessary to substitute some other controlling force than the earth's magnetism against which to balance the electric currents in direct reading measuring instruments. Such instruments are called "*Ammeters*," when they are designed to measure currents over one ampere in strength; and milli-ammeters, when designed to measure fractions of an ampere.

The controlling forces employed in the various types of such instruments have been: *Permanent Magnets;* the *Force of Gravity;* and the *Elastic Force of Springs.* In all of these different types, the law of action has varied. In some the deflection has been directly proportional to the strength of current, and only in very few cases has the law of tangent proportionality been employed, because of the practical objection to it that the *divisions are unequal* and therefore confusing to the reader. Of recent years, some of the brightest intellects amongst our physicists and electrical engineers, both at home and abroad, amongst the number being Sir William Thomson, Marcel Deprez, Siemens, Cunynghame, Ayrton and Perry, Schuckert, Crompton and Kapp, Edward Weston, Elu Thomson, and others, have been diligently at work endeavoring to design a type of ammeter which should be delicate and accurate and meet all the practical requirements of a commercial instrument. The problem has been one of the most difficult of solution ever submitted to the physicist. And yet the makers of shoddy, junk electro-medical apparatus, have flooded the market with worthless instruments that have been palmed off upon the credulity of physicians as reliable "*milli-ammeters.*" An ammeter must be an instrument that indicates in terms of the *absolute universal standard unit* at all times and in all ordinary places, or it is nothing more than a "*Galvanoscope*," which simply indicates the *presence* of a current. To be a commercially practical instrument it must possess the following qualifications:

It must have a wide range:

It must be permanently frictionless in the practical sense:

It must be absolutely "*dead-beat*;" that is, the needle must not vibrate or oscillate under variations of the current, but move promptly up to the point marking the increase or decrease in the strength of current, and there *remain* without vibration or oscillation, just as though it were being moved by a very fine threaded screw:

It must not be affected materially by variations in temperature:

Its readings should not vary materially with age:

It should read correctly for all places:

It should be *delicate* or *sensitive*, and at the same time have a *low* resistance, which is a very difficult combination:

It should be absolutely direct reading:

Its law should be, that the angle of deflection varies *directly* with the strength of current, so that the *divisions* upon the scale or dial may be *equal* in length for equal increments of current strength, in all parts of the scale:

It should be portable:

It should not require levelling or other adjustment to bring the needle to the zero mark:

Its zero mark should not require to be placed in the line of the magnetic meridian of the earth:

Its needle should be deflected over a considerable and easily appreciable distance for slight increments of current:

It should have a double scale, and an accurate means of adapting it to suit different ranges of current strength:

It should not be seriously affected by the presence of neighboring pieces of iron or magnets:

Its needle should always return promptly and exactly to the zero mark on shutting off the current, without oscillation or vibration, and there remain, without having to tap or jar the instrument:

It should, above all things, be absolutely accurate in graduation, and indicate correctly in all parts of the scale, in terms of the absolute and universally recognized standard unit of current strength:

It should not be necessary to tap the instrument in order to start the needle:

Its needle should have a very small *moment of inertia*, and should move in a very powerful controlling field:

It should not be affected by neighboring wires conveying currents:

It should *not* possess any *magnifying gearing*, because these introduce friction and add to the moment of inertia of the moving parts, and so diminish the "*dead-beat*" character of an instrument.

Of all the attempts that have been made by foreign physicists to design an instrument that would meet the above requirements or qualifications of an ideally perfect instrument, the honor of the accomplishment has fallen to our countrymen, Prof. M. M. Garver and Mr. Edward Weston, of Newark, N. J. This instrument is manufactured by the Weston Electrical Instrument Co., of Newark, New Jersey, and is known as the *Weston Ammeter*. It has been commended and adopted by nearly all of the leading electrical engineers both at home and abroad. It was designed with a view to meet the constantly increasing demand, in the commercial use of electricity, for a portable instrument of greater range, accuracy, and reliability, than had heretofore been obtainable. All previous forms of ammeters were subject to marked variations and uncertainties, resulting from high temperature errors and general defects in electrical and mechanical design and construction. The electrical, magnetic, and mechanical features of this instrument are such as to eliminate all such variable elements, and ensure permanence and reliability coupled with simplicity, extreme accuracy, and portability.

Being familiar with this instrument in its application to the commercial uses of electricity, the author of this book communicated with the Weston Electrical Instrument Co. with a view to having this Company place upon the market a modification of their commercial ammeter that would indicate *milli-amperes* and meet the *special* requirements of the medical profession. This resulted in an acceptance of our suggestions, and the construction of an instrument with modifications in accordance with our design. This instrument is illustrated in Fig. 20.

This is the first absolutely correct, direct-reading, "*dead-beat*," milli-ammeter that has ever been placed upon the market. As compared with it, all previous so-called milli-ampere meters may, without exaggeration, be said to be mere pieces of junk-shop apparatus. The use of this instrument will gladden the heart of any experienced electrologist, or even the most scientific and exacting physicist.

It is *absolutely* " dead-beat," the needle moving *promptly* up to the proper mark without oscillation, and remaining there.

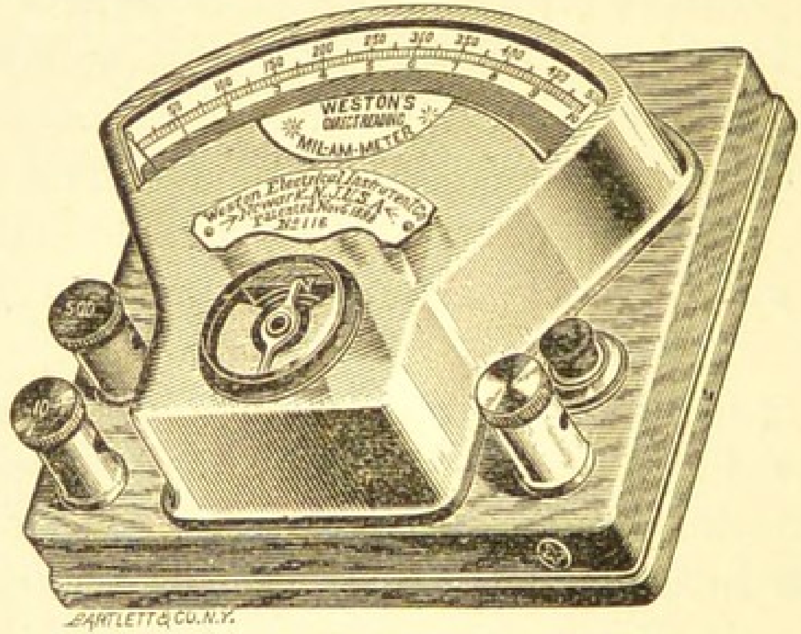

FIG. 20.—THE WESTON MILLI-AMMETER.

Made in accordance with the Author's suggestions and designs, to meet the requirements of the medical profession.

The needle always returns promptly to the zero mark.

It does not require tapping, levelling, placing in the line of the magnetic meridian, or other adjustment. It is provided with two scales, a *black* and a *red* one. The upper or *black* scale reads to five hundred milli-amperes or one-half of an ampere, each division representing five milli-amperes.

The lower or *red* scale reads to ten milli-amperes or one-hundredth of one ampere, each division representing one-tenth of a milli-ampere.

This uniform decimal arrangement of both scales greatly facilitates the readings and makes it impossible to make an error in the act of reading; for instance, in the lower scale we read one, one and one-tenth, one and two-tenths, etc., two, two and one-tenth, two and two-tenths, and so on up to ten; while in the upper scale, we read five, ten, fifteen, twenty, twenty-five and so on up to five hundred. The divisions are far apart or of great length, and easy to read, the needle moving over about $\frac{1}{16}$ of an inch to indicate only one-tenth of a milli-ampere, and over about eight inches in indicating only ten milli-amperes. By this scale arrangement the needle is generally moving in about the centre of the scale when doing electro-medical work with either the upper or lower scale, the centre of the scale representing the 250 and the 5 milli-ampere mark in the upper and lower readings respectively. The instrument is provided with three binding posts, one neutral in color for the positive wire, one black, and marked 500 for connection with the negative wire when using the upper or black scale, and one red post for connection with the negative wire when using the lower or red scale, thus making an error regarding the scale employed impossible.

All the divisions of the scale are equal in length, thus preventing confusion.

Although extremely sensitive, the resistance for both scales is very low, being for the upper scale only .19 (nineteen-hundredths) of a legal ohm, and for the lower scale only 10.43 (ten and forty three hundredths) legal ohms.

For all ordinary purposes no temperature correction is needed. The actual difference for 35° above or 35° below 70° F., is only about one per cent., being subtractive for an increase, and additive for a decrease in temperature. All these instruments are separately and individually standardized at the Weston Laboratory by a competent expert, and certified to by Mr. Edward Weston, one of the most competent and widely known electrical engineers of this country. It is a very compact instrument, and is put up in a handsome cherry box with a leather handle, which greatly adds to its portability. The author has examined and made careful tests of all the leading forms of so-called milli-ammeters now upon the market, and can without hesitancy declare this to be the only one deserving of the confidence of the profession, or which even deserves to be called a "*Direct-Reading, Dead-Beat Milli-ammeter.*" It is also so constructed that it may be turned into a *volt-meter* by simply throwing an artificial resistance into circuit with it, thus making it a combined volt and milli-ammeter. A neat little resistance box accompanying the instrument contains two resistance coils, one bringing the resistance of the instrument up to

10,000 ohms, and the other up to 1,000 ohms. When the 10,000 ohms coil is thrown into circuit, the red scale being used, the instrument will read to 100 volts, each division representing one volt, and when the 1,000 ohm coil is thrown in, it will read volts as well as milli-amperes. Here then, we have a very unique electrical instrument, measuring from a tenth

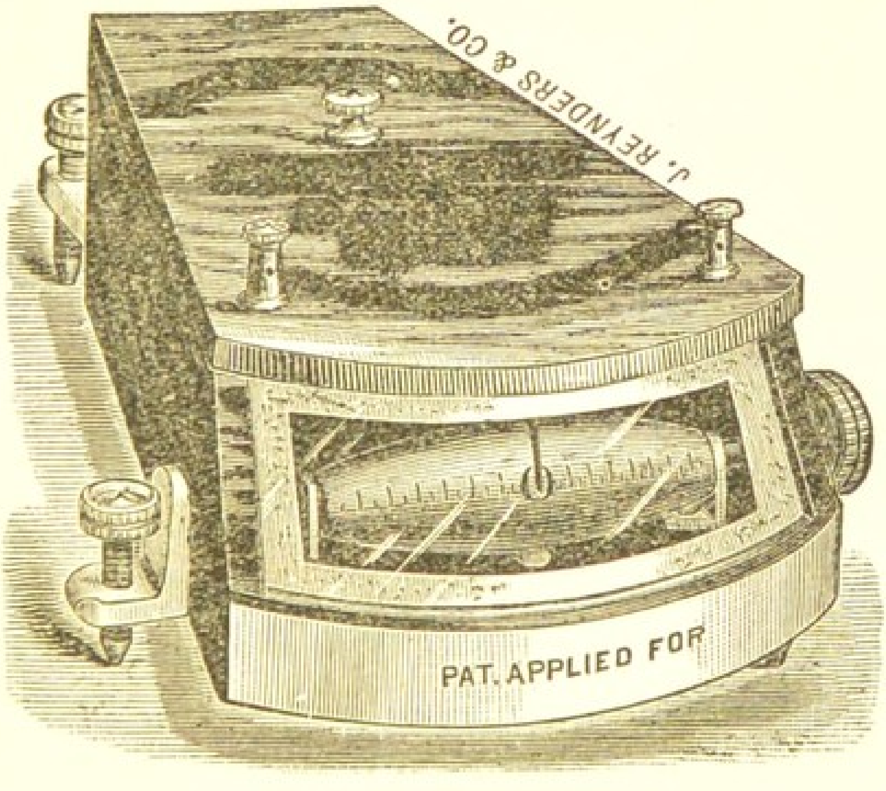

FIG. 21.—THE BARRETT MILLI-AMMETER.

of a milli-ampere to five hundred milli-amperes, and from a tenth of a volt to one hundred volts, with an accuracy seldom found even in the best physical laboratories.

The only other instrument that is deserving of mention in this category is the Barrett Milli-ammeter (see Fig. 21). This is a cheaper instrument, and compared with some of the other so-called milli-amperemeters upon the market, an admirable one; but it is neither accurate, reliable, nor "dead-beat," and compared with the Weston instrument it is almost worthless. The purchase of a cheap milli-ammeter will be found to be exceedingly poor economy in the end. It is impossible to build an instrument which will be both cheap and reliable. They require a certain amount of hand work, and the time of an expert in adjusting and callibrating them, and such labor is necessarily expensive. An instrument that has no hand work about it, and that does not require individual adjusting and callibrating, is necessarily a worthless one, and it would be better to do without any, than to rely upon such a one. We are just upon the eve of establishing electro-therapeutics upon an exact and scientific basis, in lieu of the empiricism of the past, and a false step at this period, through the use of unreliable measuring instruments, would be disastrous.

The current or milli-ampere meter should always be placed in "*series*" with the remainder of the circuit, as shown in the diagramatic illustration of the circuit connections for the Author's electro-therapeutic cabinet (Fig. 29, Vol. II). Figure 9 also illustrates a "*series*" arrangement for electrical devices. The office of the milli-ampere meter is to at all times re veal to the operator in terms of the standard unit of current strength the exact volume or strength of current that is being dealt with and which may be flowing through a patient or any portion thereof, thus enabling the operator to work intelligently and to make an exact record of the strength of the current employed in any given case, for future reference, or for purposes of publication and comparison. It is absolutely impossible to judge of the strength of current used in any case by the number of Galvanic cells employed, since the current is always a function of the relationship of the resistance of the entire circuit to the electro-motive force of the battery, and this is constantly changing and rarely the same. Ten cells may one day have twice the electro-motive force that they had upon the preceeding day, or ten cells may even one minute have twice the electro-motive force they had the preceeding minute. The internal resistance of battery cells is also constantly changing, so that a cell or a battery of cells may one moment have twice the internal resistance that they had a moment before. The degree of polarization of a battery has much to do in determining its internal re sistance and electro-motive force, and this is constantly changing, particularly in the case or open-circuit batteries. Again, the resistance of the external circuit is also subject to constant changes. The patient or subject being operated upon constitutes a part of this external resistance, and we rarely find two different subjects presenting the same resistance between corresponding points, or even the same subject presenting the same resistance between similar points upon two different occasions. The size, character and moisture of the electrodes employed, has much to do in determining the resistance; the connections at the "*binding-posts*" and elsewhere throughout the circuit, also have much to do in fixing the resistance, a poor connection at a switch or binding-post often introducing as much or more resistance than the remainder of the circuit, including the resistance of the patient.

In the construction of current meters for medical purposes, the milli-ampere, which is the one-thousandth part of one ampere, has been fixed upon as the standard unit of calibration, because this unit and its multiples correspond to the strength of the currents used in medical applications of electricity. For example, the resistance of those parts of the human body included between medium sized electrodes applied to the spots commonly selected, averages from one to four thousand ohms, and a current of one milli-ampere would be yielded by one to four Daniell's cells, and this is *about* the weakest Galvanic current ever used therapeutically or diagnostically.

In dealing with drugs we use and speak of solutions of a certain strength, and we use solutions of various strengths for the production of different effects; the strength of any solution is, however, no indication whatever of the *dose* or *quantity* of the drug which may have been administered. In like manner in dealing with electricity we use and speak of currents of a certain strength, and we use currents of various strengths for the production of different effects; here also, the strength of any current is, however, no indication whatever of the *dose* or *quantity* of electricity which may have been administered. Just as in the case of drugs, the dose of electricity is a question of the *quantity* administered at any one time, and this is not alone dependent upon the strength of current employed. To two different subjects we may wish to administer the same dose or quantity of electricity, and yet employ currents of widely different strengths in the two cases, using in the one case, for example, a current of ten milli-amperes, and in the other one, a current of one hundred milli-amperes. In dealing with solutions of drugs we employ graduates for measuring out the quantity to be employed.

The Coulombmeter is an instrument capable of performing an analogous service in the case of electricity. This instrument, and not the milli-amperemeter, as some writers have stated, measures the *dose* or *quantity* of electricity employed.

An instrument of this character has recently been constructed and placed upon the market by M. Gaiffe, of Paris, see Fig. 22. It is made of two glass tubes, one within the other, which are designed to be filled with water, and corks placed in their respective mouths. The current passes into the instrument through one of the platium wires (F), then through the water across to the other platium wire (F′)

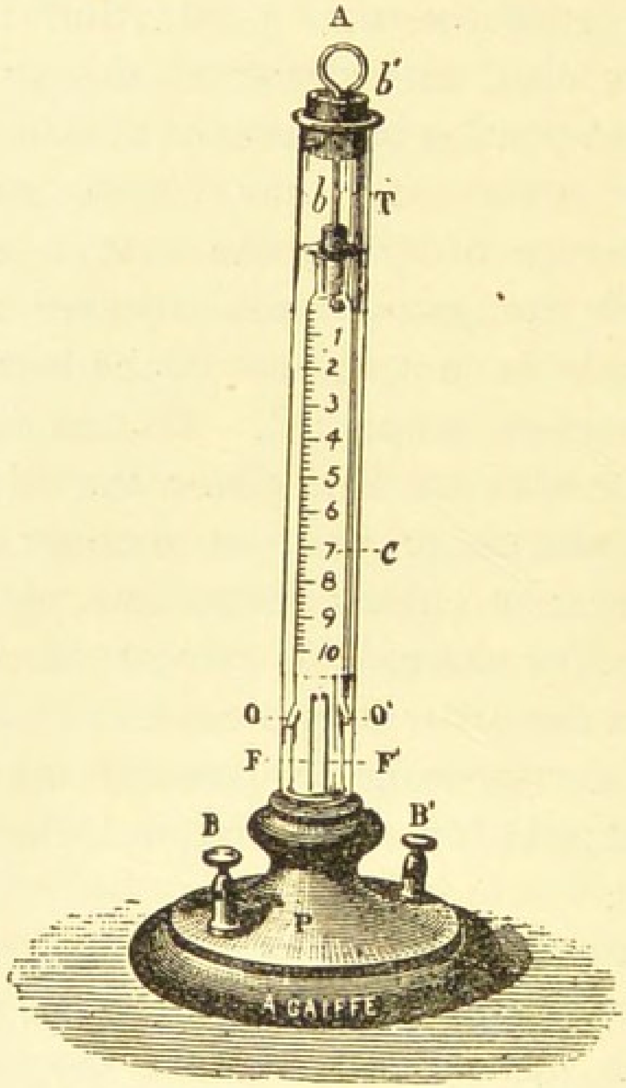

Fig. 22.—Direct Reading Coulombmeter.

T outer tube, C inner tube, both fixed to a stand, P. —*b* and *b′* corks closing the upper extremities of the tubes. *b* can be lifted out of the inner tube by pulling the wire A which passes through the cork *b′*.

O, O′ apertures in the inner tube; F, F′ platinum wires projecting into the inner tube and connected with the binding screws B, B′ to which the wires of the external circuit are attached. The inner tube is graduated so as to read directly in coulombs.

and so out, in its passage decomposing the water into oxygen and hydrogen, which ascend in the inner tube and collect at the top, thus depressing the water in the inner tube, the level of which marks the number of coulombs passed through the instrument. After the instrument has been used, and gas has formed within the inner tube, expelling a portion of the water, equilibrium may be re-established and the water from the outer tube caused to flow back into the inner one, by simply lifting the inner cork by means of the wire (A), when the instrument will be ready for another measurement. A small quantity of water must occasionally be poured into the outer tube, so as to insure the refilling of the inner tube when its cork is raised.

This instrument reads directly up to ten coulombs. In ordinary neurological work the doses range from ½ to 6 coulombs, while in gynecological work they range from 4 to 200. This instrument does not read high enough, and possesses too high a resistance, for use in gynecological work, without the addition of a "*shunt*" circuit or by-path around the instrument, of comparatively low resistance, such as will multiply the reading say twenty times, which will enable it to read up to 200 coulombs, and at the same time decrease the resistance, so as not to consume an undue amount of the available electro-motive force. A switch may be introduced to throw in and out this "*shunt*"-*circuit.* With such an arrangement we measure a certain per centage only of the total current employed, say $\frac{1}{20}$th. Such an arrangement is shown in the diagrammatic illustration of the connections for the authors' cabinet, Fig. 29, Vol. II.

By the use of this instrument, then, in conjunction with a milli-ampere meter, we may observe and record the fact that at certain specified intervals we administered to a patient for some particular affection, in a particular manner, so many coulombs of a constant or continuous current of electricity of an "*intensity*" of so many milli-amperes;* do not however confound this word "*intensity*" with the term "*tension*," as is so frequently done.†

The term "*intensity*" is used in France to indicate the strength or volume of a current of electricity, and is synonymous with the term "*current*" as used in

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* Just as when dealing with drugs we speak of having administered a certain "*quantity*"–say so many drops or teaspoonsful–of a solution of a certain "*strength*"–say five, ten or twenty per cent. or even a saturated solution of a particular drug, at specified intervals. Here, then, we have presented a means of dealing with electricity as a remedial agent in a scientific and precise, rather than in the empirical manner of the past. The possibilities and the developments which such a method promises, must be at once apparent to any accurate observer.

† For instance, Bartholow in his work on "Medical Electricity," page 37, says: "By *intensity* of a current is meant its power of overcoming resistance." Others make the same error.

this country. In France, for example, they write "*intensity*" or $I. = \frac{E}{R}$, while in this country we write "*current*" or $C = \frac{E}{R}$.

The term "*tension*," on the other hand, is employed to designate the pressure or head under and by virtue of which a current of electricity flows, and is synonymous with the term "*electro-motive force.*" A clear comprehension of this distinction will elucidate much of the existing confusion to be found in current writings.

THE VOLT-METER is nothing more or less than an ammeter constructed of extremely fine wire, so as to have a very high resistance as compared with other parts of the circuit. It gives by direct reading the value in volts of the difference of potential across terminals or between any two points of a circuit between which it may be inserted as a "*shunt.*" It should possess the same qualifications specified as essential in a good ammeter. In the author's adaptation the Weston ammeter, the coil of wire for the red or ten milli-ampere scale is the same as that used in the Weston volt-meter, so that by the introduction of a suitable additional resistance outside, this instrument maybe converted into a volt-meter, thus presenting two instruments in one. A neat little resistance box has been made for the writer at his instance by the Weston Co, containing two separate coils of wire which bring the resistance of the instrument up to one and ten thousand ohms respectively (See 12, Fig. 28, Vol. II).

When the one thousand ohm coil is thrown into circuit with the coil for the red scale, the instrument reads in volts as well as milli-amperes, reading up to ten volts, each division representing a tenth of a volt. Throwing the ten thousand ohm coil into circuit with the coil for the red scale, enables the instrument to read up to one hundred volts, each division representing one volt. This makes a very unique instrument—a combined volt and ammeter, measuring from a tenth to 500 milli-amperes, and from a tenth to 100 volts, with an accuracy seldom found even in the best physical laboratories.

The volt-meter is of service in determining the electro-motive force of individual cells and of the entire battery or source of supply; in determining whether our storage battery needs re-charging; in determining the proper number of cells to use in connection with certain electric illuminating instruments; and in determining the difference of potential across any two points at which we may be applying a current to a patient, from which we may arrive at the resistance of the parts, and thus check up measurements which we may probably also have made with the "*resistance-box.*" To one who wishes to follow in beaten paths and rely wholly upon the assertions of others, the volt meter is of but little use. To one, however, who wishes to be an original investigator, proving and correcting the assertions of others, mapping out new paths, checking up his own investigations, and inventing new appliances and methods of treatment, a volt-meter is indispensible.

The Ohm-meter or Box of Standard Resistances, is as essential for the intelligent dealing with electricity and the manipulation of electrical apparatus, as are the level and compass respectively to the builder and mariner. Electrical resistances are generally measured by balancing a known against an unknown resistance, through the agency of what is termed the *Wheatstone bridge*, but since this is not suitable for medical purposes, the writer will not burden this small book with a description of it. Direct reading "*ohm-meters*" that can be placed directly in the circuit, partly in "*series*" and partly in "*shunt*," and from which the resistance of the circuit may be at any time read off directly in ohms, have been proposed by Werner Siemens and Fleming Jenkins, and constructed by Prof. Ayrton, nevertheless we have never seen one, and are not aware that any have as yet reached this country. It is possible these may prove most suitable for the purposes of the electro-therapeutist. The best method with which we are at present acquainted is, however, what is known as the *Substitution* method, which consists in the act of withdrawing from the circuit the unknown resistance to be measured, and gradually substituting a known resistance, until we bring the current back to the same strength that it had in the first instance, this being indicated by the reading of the ammeter included in the circuit. The amount of known resistance introduced will then be equal to the unknown resistance which has been withdrawn. This "*known resistance*" should be made up of a suitable variety of coils of fine German-silver wire, made by some reliable physical apparatus maker, and having values varying from $\frac{1}{10}$ to 10,000 ohms, arranged in such a manner as to enable the rapid selection of any intermediate number of ohms for introduction into the circuit.* The author has designed such a *standard resistance-box* in connection with a suitable device and arrangement for conveniently and rapidly throwing into circuit any required amount of resistance between $\frac{1}{10}$ and 10,000 ohms, and this constitutes a part of the cabinet shown in Fig. 28, Vol. II., being depicted at 6 in the illustration. The required resistance is introduced by a proper manipulation of the two arms and the plugs. Standing as shown in the illustration, it is in circuit ready for use, but all resistance is "*short-circuited*" (cut out) by the arms. To introduce any required amount of resistance we have only to move the arms to the proper position, and properly insert one or more of the plugs into the proper holes between the buttons.

In the practice of both electro-diagnosis and

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* What are ordinarily called "*rheostats*" will in no manner serve this purpose, since they are not designed for it, not being made properly, and the coils not possessing standard values.

electro-therapy, we frequently have occasion to determine the comparative resistance of the tissues and muscles upon the two sides of the body, and to compare the resistance of these at one time with their resistance upon another occasion. But this is not its only value; we *constantly* have occasion to use a method of measuring electrical resistance in checking-up and proving our observations. The absence of, and failure to use, such devices and methods, on the part of would-be practitioners of electro-therapy in the past, has constituted the one potent instrumentality for the introduction of the hundreds—yes thousands—of fallacies which we find in electro-therapeutic literature.

THE ADJUSTABLE RHEATOME is a device for interrupting the circuit any required number of times per minute. The Du Bois-Reymond induction coil, presently to be described, has attached to it a slow interrupter for varying the rapidity of the inductions, but it provides no means of knowing the number of interruptions it makes per minute. In treating the various forms of paralysis and in making electrical diagnoses, it is very desirable to have a ready means of interrupting either the Galvanic or Faradic circuit any required number of times per minute, so that we may make a record of the results obtained under these varying conditions. We may wish, for instance, to record the fact that at the beginning of the treatment of a particular case of paralysis, certain muscles responded to say sixty impressions or impulses per minute of a twenty milli-ampere Galvanic current, and after a month of treatment these same muscles responded to one hundred impulses per minute of a ten milli-ampere Galvanic current, showing a "*modal*" change; or we may wish to make a similar record regarding the action of the Faradic current. Again, we often wish to send a series of rhythmical shocks with varying periods of intermission through portions of the central nervous system, with a view to producing a profound impression.

The best instrument of this kind now upon the market is manufactured by the McIntosh Battery Co., of Chicago, and is depicted at 13 in Fig. 28, Vol. II. The arrangement of circuits should be such that this rheatome will be permanently connected with both the Galvanic and Faradic circuits without interfering one with the other.

The Faradic or Induction Coil should have a wide range, possess an attachment for both rapid and slow automatic interruptions, a hand-switch for opening and closing the primary or battery circuit, a switch for throwing into circuit either the primary or secondary coil, and some suitable means of varying the electro-motive force of the generated current. An admirable instrument which fulfills these requirements is manufactured by the Law Telephone Co., of New York, see Fig. 23. This instrument has an extra large coil, which gives a wide range of electro-motive force. It is particularly adapted for office work. The current is varied by moving the secondary coil towards and away from the primary one, through the agency of a rack and pinion device. When the secondary coil is entirely removed from over the primary one, the current from the secondary coil is at its weakest, and that from the primary coil is at its strongest; the reverse being the case when the sec-

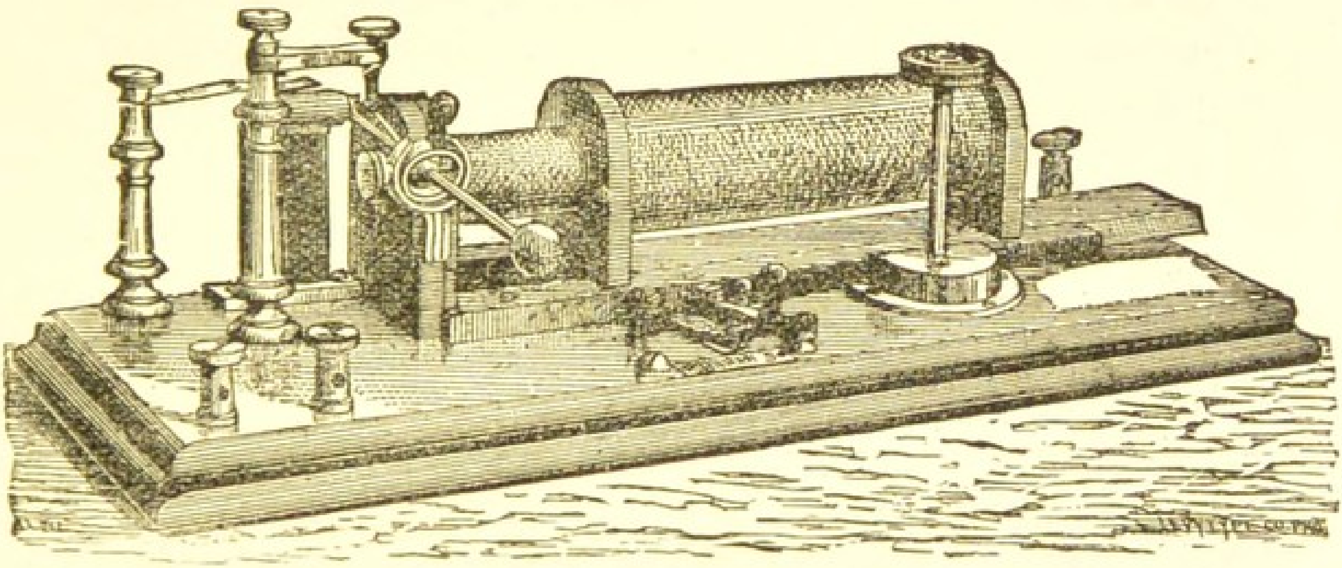

Fig. 23.—Du Bois-Reymond Coil. Manufacturedby the Law Telephone Co., N. Y. This coil has a switch for opening and closing the primary circuit, which is not shown in the cut.

ondary coil completely covers the primary one. A double scale aranged parallel with the axis of the coils is supposed to enable the operator to reproduce a given current or one corresponding in strength to one which may have been employed upon some previous occasion, but it is misleading. Although we may place the coils in exactly the same position with relation to each other upon two different occasions, we do not thereby necessarily secure the same current, for this is governed by many other factors, for instance, the strength of the battery current energizing the primary coil, the character of the interrupter contacts, the number of interruptions per minute, and the resistance of the external circuit, including the patient, electrophores or conducting-cords, electrodes, switches, etc. The only way of knowing anything definite about the strength of the current from an induction coil, is through the agency of a current meter specially designed for the measurement of the weak alternating currents such as are generated by medical induction coils. This has not heretofore been done, but it is nevertheless possible and has been accomplished by the author. In the instrument here illustrated, the primary coil is made up of 150 feet of No. 18 wire, and the secondary coil of 3,400 feet of No. 36 wire. The secondary coil gives a mean current upon a short circuit of from $\frac{1}{20}$ to one milli-ampere. Dr. G. Betton Massey of Philadelphia, who has written one of the most practical and accurate special works on electricity in medicine that has been written up to this date, makes the following statement upon page 86 of his book.

Experimental proof of the inappreciable volume of Faradic currents. (*Experiment* 15.) Place a milli-ampere meter in circuit with the secondary coil by including it directly between the poles of the battery, and turn on the full strength of the current; the meter will not show even the fraction of a milli-ampere.

This conclusion is erroneous, because the premises are wrong. It is assumed that the ordinary milli-ammeter is adapted to the measurement of the "*alternating*" current, such as is generated by an induction coil. Whereas, as a matter of fact, the ordinary milli-ammeter is only designed for the measurement of continous currents flowing in one particular direction. If an alternating current from a commercial induction coil of sufficient strength to operate ten 100 volt 16 candle power incandescent lamps, had been caused to flow through this measuring instrument (assuming the wire capable of carrying it), the result would have been the same—the needle or indicator would have stood still—and yet about seven thousand milli-amperes would have in this case been flowing through the instrument., The volume of the current from a medical induction coil, is of course, small, but it is nevertheless appreciable, and can be measured in terms of the same unit that we employ in measuring the Galvanic current.

The greater the volume of a current *flowing through* a muscle, the more violent is its contraction; but the mere fact of a *coarse-wire* coil being used, does not indicate that a current of great volume has been sent *through the muscle.* The volume of the current sent *through the muscle* is purely a question of the relationship of the resistance of the parts to the electro-motive force of the current. In one case, a *fine-wire* coil will give the more violent contractions, and a *coarse-wire* coil less violent contractions, while the reverse will be true in another case. A number of coils of different sized wire are, then, only of advantage in *increasing the range* of our battery, or of our available electro-motive force. A current of small volume and high electro-motive force, such as will *ordinarily* be derived from a coil made up of fine wire, will be less serviceable as a muscle contractor, and more serviceable as a stimulant and for the relief of pain, not because the wire is *fine* or because the current generated from a *fine*-wire is necessarily different from that generated from a *coarse*-wire, but because there are a greater number of convolutions or turns of the fine-wire to be cut by lines of force, which increase the electro-motive force, while the long coil of fine-wire offers so great a resistance that the resulting current is cut down to a very small volume. It should, therefore, be apparent that the same results that would be derived from a number of *small* coils made of different-sized wire, may be secured by the use of one *large* coil made of medium sized wire, with means for introducing a variable resistance into our external circuit, such as is afforded by the current controller already described- The induction coil illustrated in Fig. 23, in conjunction with the current controller, which should be arranged to be introduced into circuit with it at will, and with the induced current to be derived from the static machine to be described in Vol. II, will furnish as great a range of currents as could be desired for all medical purposes. The slow and rapid interruptors of this coil are admirable pieces of mechanism, and in every other respect it is a superior piece of apparatus, both physically and mechanically.

While there is *physically* no difference between the poles of a Faradic coil, since the positive and negative poles are constantly alternating between the two binding-posts, the changes occuring with each alternation or change in the direction of the current, which take place with each make and break of the primary circuit, there is, nevertheless, a great difference *physiologically*. This paradoxical statement will be understood when it is explained that only one of the induced currents (that which is made on breaking the primary or battery circuit) has any appreciable nerve or muscle contracting power, and this, of course, always flows in one particular direction. This arises from the fact that the phenomenon known to electricians as *self-induction*,* operates to cut down the electro-motive force of that induced current which is generated on making the primary circuit, to such an extent that it has not the necessary

*See articles 908, 910 and 923, pages 834, 836 and 859 respectively in Ganot's Physics, 1883.

pressure to force itself through the tissues of the human body. Let us now see how this explanation suits the phenomena as we find them: Attach two electrodes to the secondary wire of a Faradic coil; now place the electrode attached to the pole marked positive upon some indifferent part of the body—either the calf of the leg or the thigh—and the other or negative electrode over the motor point for the *tibialis anticus*. Now throw into circuit the slow interrupter, close the primary circuit, and then gradually increase the electro-motive force of the secondary circuit by moving the secondary coil further and further over the primary one, up to the point where the *tibialis anticus* just begins to contract; now reverse the poles by means of a pole-changer, without removing the electrodes,—this makes the electrode over the motor point a positive one; no contraction of the muscle will now be observed. Now make an abrasion of some portion of the body and place the negative electrode upon it, the positive electrode resting upon any other part of the body; turn on the rapid interrupter, and gradually increase the secondary current, as before, up to the point where considerable pain and irritation is felt at the point of abrasion; now reverse the poles, as before, keeping the electrodes *in situ*,—this makes the electrode over the abrasion, positive, and no pain or irritation will now be felt at this point, but rather a soothing effect. This would seem to prove that there is but one current and that it flows in one particular direction, making a positive and negative pole, which act differently upon both sensory and motor nerves, just as in the case of a Galvanic battery. Let us now remove the electrodes and connect the electrophores or cords to our milli-ampere-meter or Galvanometer, screwing down the contact screw tight upon our rapid vibrator, then make and break the primary or battery-circuit of our induction coil by means of the hand-switch; we shall observe a throw of the meter-needle in opposite directions with each make and break of the circuit, and the degree of deflection will be about the same for both the make and the break, leading us to conclude that a current is generated in the secondary coil both with the make and the break in the primary circuit, and that these currents are of about the same volume, and that they flow in opposite directions, thus constantly changing the polarity of the coil, which is, physically speaking, neither positive nor negative. Both these sets of observations—the physiological and the physical—are correct, nothwithstanding their apparent contradiction. One current, that which is generated upon making the primary circuit, has so low an electro-motive force that it acts like one cell of a Galvanic battery, failing to overcome the *high* resistance of the tissues and cause the flow of enough current to excite sensory and motor impressions, while it has ample electro-motive force to set up a sufficient flow of current through the *low* resistance of our meter to induce a deflection. Therefore, while it is not physically proper to mark the poles of an induction coil as negative (N) and positive (P), it is physiologically proper to mark them as anodal (An) and kathodal (Ka), since such a coil produces but one physiologically active current which flows in one particular direction, and, with the exception that it is intermittent and (as ordinarily produced) of comparatively small volume, presents the same characteristics as an ordinary Galvanic current. The only physical difference between a Galvanic and a Faradic current, consists in the fact that the former may be *continuous*, while the latter is, of necessity, *intermittent*; as regards their respective volumes and electro-motive forces, there is not *necessarily* any difference, since the one may be made to have the same volume and electro-motive force as the other, although as we generally employ these, the Faradic has the lesser volume and greater electro-motive force. If we take two intermittent currents, the one a Faradic and the other a Galvanic, the intermissions of each occuring with the same periodicity, and the electro-motive forces and volumes of each being identical, and apply them in every possible manner to living tissues, we find that the one produces in every instance exactly the same physiological phenomena as the other. We find, then, that the widely varying physiological phenomena which are known to accompany the exhibition of these two so-called different forms of electricity, are entirely due to the varying conditions under which one and the same form of energy is administered, and that these varying conditions have reference to the electro-motive force, volume, and degree of constancy or intermittency, of the current. *How important it is, then, to be provided with apparatus and instruments of precision, for producing and determining these conditions with absolute accuracy.* In evidence of the chaotic and contradictory notions which prevail concerning this subject, we will quote from Dr. George J. Engelmann, who is one of the most recent and scientific of writers upon the subject, and this without intending any uncomplimentary reflection or criticism upon his work, which has been of a most laudable character, the profession of America owing him much gratitude for his early and scientific presentation of the modern methods of using electricity in gynæcological practice. On page 37 of his monograph entitled "The use of Electricity in Gynæcological Practice," Dr. Engelmann, in speaking of the Faradic current, says:

"A difference between the therapeutic effects of the two poles I have not discovered * * * * I shall, however, continue my observations, as I am by no means fully satisfied as to their identity." And again on page 19 he says:

" Striking as is the difference between the effect of the positive and negative poles of the constant current, diametrically opposed in their chemical action, I have discovered no difference between the poles of the Faradic interrupted current, when used as such, *and it is natural that it should be so, as with each interruption the current springs from pole to pole—to and fro.*" * He, however has observed and admits the clinical fact that one pole produces an irritation and pain that is not produced by the other pole, since he continues by saying: "The negative pole is, however, the more intense and painful."

On page 38 we find this statement: "It is a grievious fault of the Faradic batteries made for medical purposes that they cannot be sufficiently regulated; the *strength of the current only can be changed*, but the most important feature, the tension of the current, is fixed." From the explanations and descriptions already given it must be apparent that this is a gross error. That is just what we do—vary the tension or electro-motive force of the Faradic current—when we move the secondary coil to and away from the primary one. Dr. Engelmann admits that this varies the "strength" of the current. Now pray tell how is this accomplished in the face of Ohm's law $C=\frac{E}{R}$ (current equals tension divided by the resistance) without varying the tension when the resistance remains the same, as is always the case? This is a mathematical

* The author has italicized this portion.

problem the writer would like Dr. Engelmann to solve for him. Surely, if C changes, we must change the value of E, when R does not change. We will now prove the error by a practical experiment, for the benefit of those who are not sufficiently versed in mathematics to appreciate the force of the above reasoning. Attach two electrodes to the secondary wire of Engelmann's finest or longest coil, place one electrode in each hand, now move the secondary coil gradually over the primary one, up to the point where the current just begins to be appreciable—suppose this to be 35 mm. from 0. Now remove this coil and place Engelmann's coarsest wire or shortest coil in the same position, we find that the current is not appreciable. Why? Because the tension or electro-motive force of the first or longest coil was high enough to create a flow of current through the high resistance of the body of sufficient strength or volume to produce a sensory impression, while that electro-motive force set up by the second or shorter coil when in the same position with respect to the primary coil, was not sufficient to set up through the same resistance a current of similar strength. The fine wire or long coil, therefore, gives the greater tension, strictly in accordance with Engelmann's views. But let us now move the second or short wire coil a little further up the scale—say to 40 mm. from 0, where we find that the current again becomes appreciable and feels just as it did when coming from the long wire coil when at the position marked 35 upon the scale. We have here produced the same increase in the tension of the current by simply moving the coarser secondary coil further up the scale, thus bringing more convolutions or turns of wire into the magnetic field to be cut by lines of force. Moving the shorter wire coil up the scale, is, then, equivalent (up to a certain point) to substituting a longer wire coil, as far as the tension or electro motive force of the current is concerned. The resistance remaining the same, as in the latter experiment, it is a physical impossibility to increase the strength of the current without increasing the tension or electro-motive force; *this is a proposition that can not be gainsaid.*

In another place, upon page 38, Dr. Engelmann says:

"The *tension* of the current is a quality possessed by Faradism in a higher degree than by any other form of electricity."

This is likewise an erroneous idea. Any of the other *so-called* forms of electricity may be caused to have the same electro-motive force (*tension*) that the Faradic current may have, and as we meet with them in medical practice, the *so-called* static machine produces currents of an infinitely higher electro-motive force (*tension*); for instance, the ordinary medical induction coil will only produce an electro-motive force (*tension*) of from 50 to 100 volts, at the outside, while the *so-called* static current has an electro-motive force of 60,000 volts and upwards, and it can be used for the same purposes as the Faradic current, and under appropriate conditions may serve as the most powerful muscle contracting agent that we have at our command, notwithstanding its inappreciable volume even on a "*short-circuit.*"

One cell of the new double-cylinder "Law" battery is sufficient to operate the Du Bois-Raymond induction coil shown in Fig. 22, and this will prove the best type of cell for this purpose.

THE FARADOMETER is an entirely new electrical measuring instrument, invented by the author for the measurement of Faradic currents: The term "*Faradometer*" has been coined as most suitable for its designation. It is a direct-reading, dead-beat instrument; is not affected by ordinary extraneous inductive influences, and; does not have to be leveled or placed in any particular position. It is very sensitive and reads up to one milli-ampere by hundredths, each of the smallest divisions indicating one one-hundredth of one milli-ampere. The need for such an instrument has long been recognized by the most advanced electro-therapeutists, but until now it has not been forth-coming. The accompanying illustration, Fig. 24, gives a very clear conception of its external appearance and a fair idea of its internal construction. A description of the details of its construction and the principle of its operation would be rather too technical for the present work. It is placed directly in circuit (series) with the secondary wire of the in duction-coil, as shown in Fig. 29, Vol. II, the current being led in at the binding-post A, and out at the binding-post B, Fig. 24. It may be included in the circuit or short-circuited (excluded from the circuit) by withdrawing and inserting a metallic plug into the

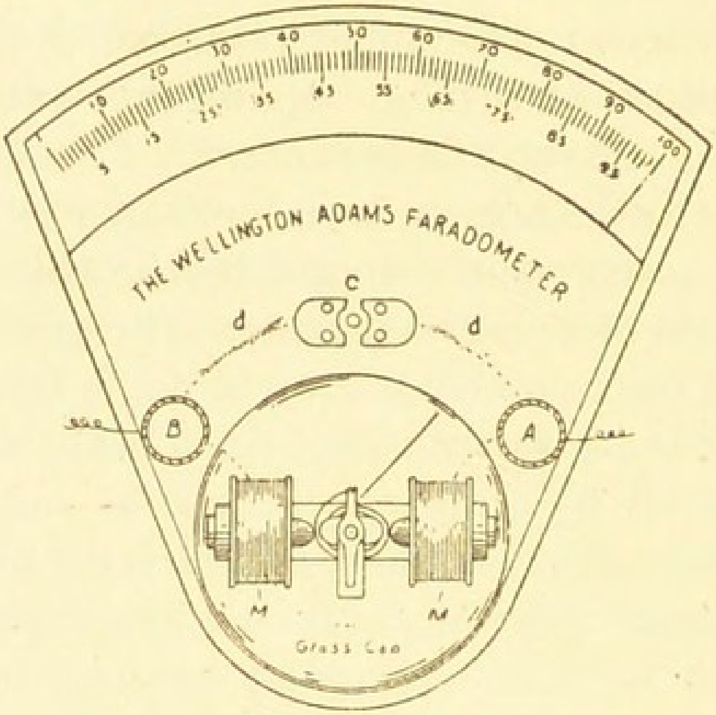

Fig. 24.—The Wellington Adams Faradometer.

hole C; when the plug is in, a *short-circuit* or by-path is established through d. d., and the current is thus "*shunted*" or switched around the instrument, and it does not operate, while when the plug is removed, the current passes through the magnets m. m., thus operating the instrument normally to measure the strength or volume of the current being sent through the tissues, but by adding a suitable resistance and connecting the binding-posts A and B to the terminals of the induction coil, at the same time that a current is being sent through a patient, the *tension* or electro-motive force of the current may likewise be measured directly in volts. With this instrument at our command we can observe and record the qualities—tension and volume—of the Faradic current used upon a patient, in terms of the standard units—the volt and the ampere. The "Weston Electrical Instrument Co." of Newark, N. J., expect to undertake its manufacture.

The introduction of the Faradometer is certain to mark a new era in the history of electro-therapeutics.

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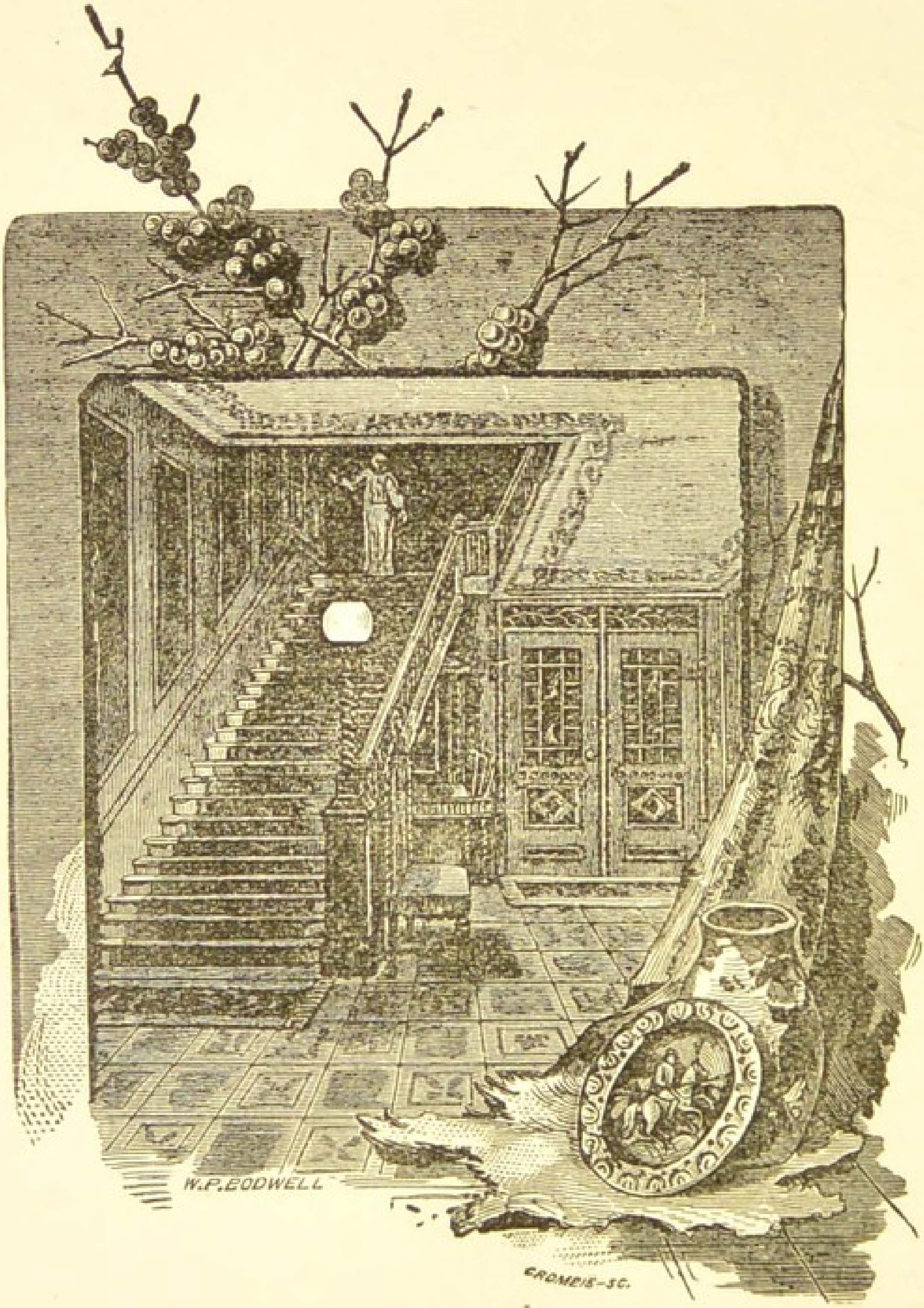

"A Modern Night-Call."

ELECTRICITY

Its Application in Medicine and Surgery.

A Brief and Practical Exposition of Modern Scientific Electro-Therapeutics.

— BY —

WELLINGTON ADAMS, M. D.,

Author of "Art of Telephony—By Whom Discovered;" "Evolution of the Electric Railway;" "Design and Construction of Dynamo-Electric and Electro-Dynamic Machinery;" Lecturer on Electro-Therapeutics, University Medical College, Kansas City; Formerly Professor of Diseases of the Ear, Nose, and Throat, Medical Department, University of Denver, and Editor "Rocky Mountain Medical Review."

VOLUME II.

1891.
GEORGE S. DAVIS,
DETROIT, MICH.

This little book is, by permission, respectfully dedicated to

FRANCIS E. NIPHER,

Professor of Physics in Washington University, whose unselfish devotion to the cause of science has commanded the author's admiration and respect.

VOLUME II.

CHAPTER I.

FORMS OF ELECTRIC MACHINERY AND THEIR APPLICATION.

ELECTRO-STATIC INDUCTION MACHINES are designed for the production of currents of extremely high electro-motive force and very small volume. They are all constructed upon the principles involved in the production of what has been called "*Frictional*" or "*Static*" *electricity*, although these terms are both too narrow and restricted for the accurate designation of the involved phenomena. The term *frictional* has been used because friction is one of the principal agencies by which this character of electricity is generated; while the term *static*, from the Latin *sto*, "to stand," has been adopted because this character of electricity is generally stationary. But it is neither always generated by friction nor always stationary. It may be generated in other ways, and it may flow just like any other form of electricity, and is subject to the same laws with respect to electro-motive force, resistance and volume. The peculiar and special phenomena involved in its manifestations may be demonstrated by reference to Fig. 1, which illustrates the pith-ball electroscope. A horizontal brass arm is here mounted upon an ebonite insulating stand. From this arm two pith balls are suspended by silk threads, considerable space intervening between them. If a stick of sealing-wax

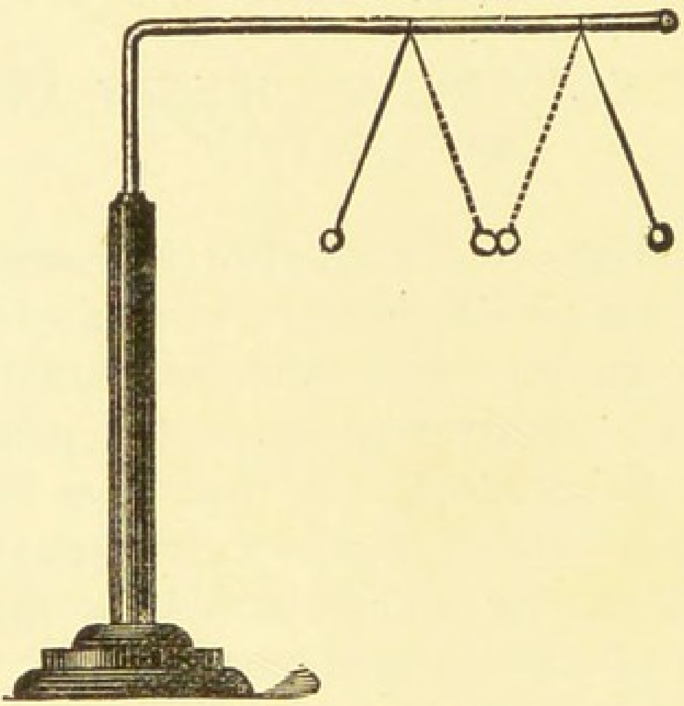

Fig. 1—The Pith-Ball Electroscope.

be now electrified by friction with a silk-handkerchief, and brought near one of these balls, the latter will be attracted to the wax, and, after a momentary contact, repelled. If followed up with the wax, it continues to recede as if pushed back by some invisible power. If the other ball be now approached to the first one, both will be attracted to each other, and, after contact, repelled, the suspending threads showing a divergence in each direction. If the electrified wax be again brought near, both balls will be repelled by it; but if a non-electrified body be brought near the balls, they are attracted to it. If each of the balls be separately electrified by the wax, and then brought near each other, there will be mutual repulsion without previous attraction.

From this series of phenomena it is demonstrated, first, that bodies may be electrified by *friction*; second, that they may be electrified by *induction*, or by close proximity to bodies already electrified; third, that electrified bodies not only attract non-electrified bodies, but communicate electricity to them by contact; and fourth, that bodies similarly electrified, either by each other or from the same source, show mutual repulsion.

These phenomena constitute the underlying principles involved in the construction of all frictional and influence machines, and in the manifestation of what is called *static* electricity. The terms used to distinguish the different clases of electric phenomena, as *Frictional*, *Static*, *Galvanic*, *Chemical*, *Magnetic* and others, originate from the different methods by which electricity is generated, and the varied conditions under which its phenomena have been observed, and must not be understood as referring to any difference in the nature of the electricity produced.

A static machine is simply an aggregation of electrical and mechanical elements for the generation, collection and conservation of a series of just such electrical changes as were produced on rubbing the sealing-wax. The first machines of this class operated upon the principle of friction purely, were

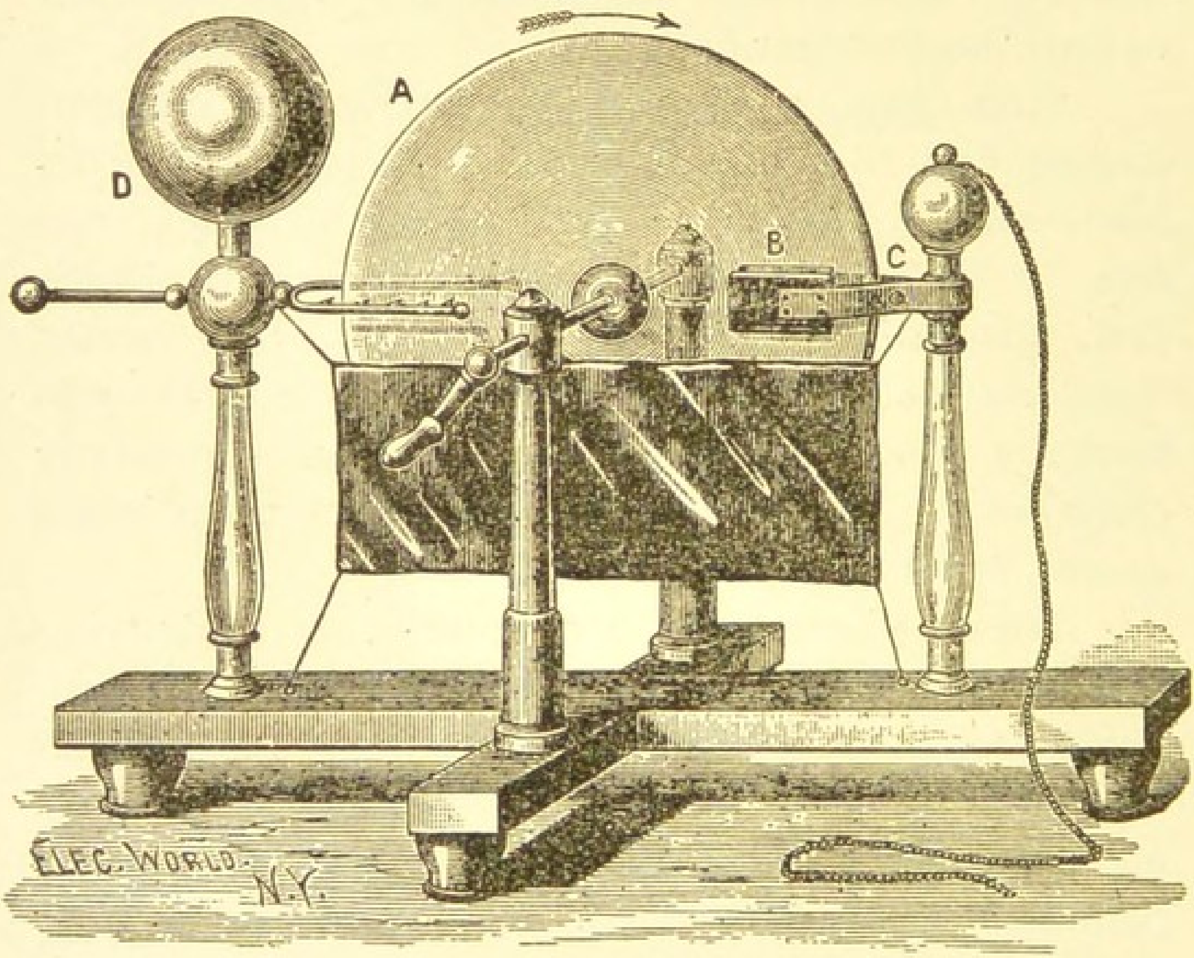

Fig. 2—Plate Electrical Machine.

known as "frictional" machines, (see Fig. 2), and which shows one of the earlier forms invented about 1787.

Prior to 1865, frictional machines were the principal electro-static generators in use. That year, however, brought great progress, in the shape of the invention of two new machines of remarkable energy and efficiency.

First came the Holtz machine, shown in Fig. 3, which is purely an *influence* machine, operating upon the principle of *induction*, being constructed with two

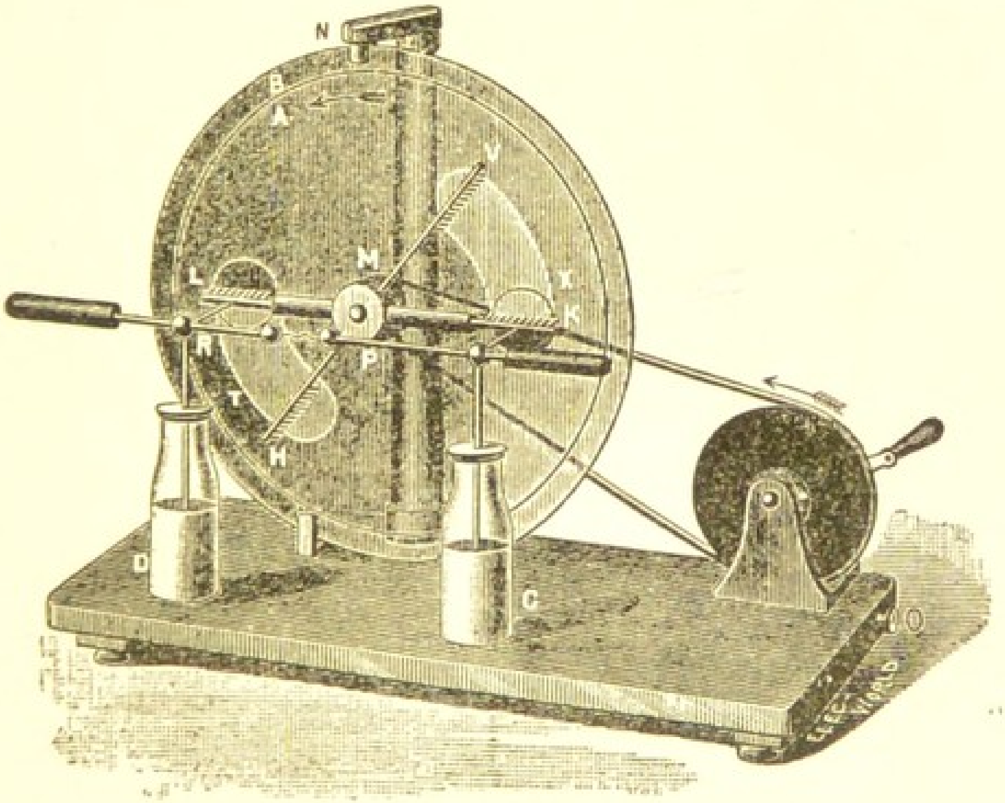

Fig. 3—The Holtz Electrical Machine.

glass plates arranged to generate electricity by their mutual inductive influence. This machine had to have an initial charge placed upon the "*inductors*" (T. X.) on the back or stationary plate, every time it was to be used. This charge acted inductively upon the front or revolving plate with increased force, and this again reacted upon the back plate with still greater force, this cumulative and reactive action continuing till a charge of very high potential resulted. Next came an improvement by Töpler, which, in the main, consisted in an arrangement for making the machine self-charging and cumulative like the modern *dynamo* or electric light generator. A modern form of this machine is represented by Fig. 4. This improvement was brought about by the mounting of six little round metallic caps or "*carriers*" (c. Fig. 4) upon the front or revolving plate, and the provision of two metalic brushes (a. b. Fig. 4) to rub against these carriers. These "*brushes*" rub against the "*carriers*" when the front plate is revolved, and generate an initial charge, which is conveyed to the *inductors* (A. B.) upon the back or stationary plate, and thus *charge* the otherwise Holtz machine, which then continues the action in the manner already described when speaking of the latter machine.

The Töpler generator constituted a great advance in the evolution of static machines, and in all the years that have followed its introduction, but little in the way of an *electrical* improvement of this machine has been inaugurated, although the Wimhurst machine (see Fig. 5) which has very recently made its appearance, is claimed to be something of an improvement over it.* This machine consists,

*This machine has been placed upon the market by the Electrical Supply Co., of Chicago.

primarily, of two revolving glass discs, placed near together, each having an equal number of metallic sectors or "*carriers*." These discs revolve in oppo-

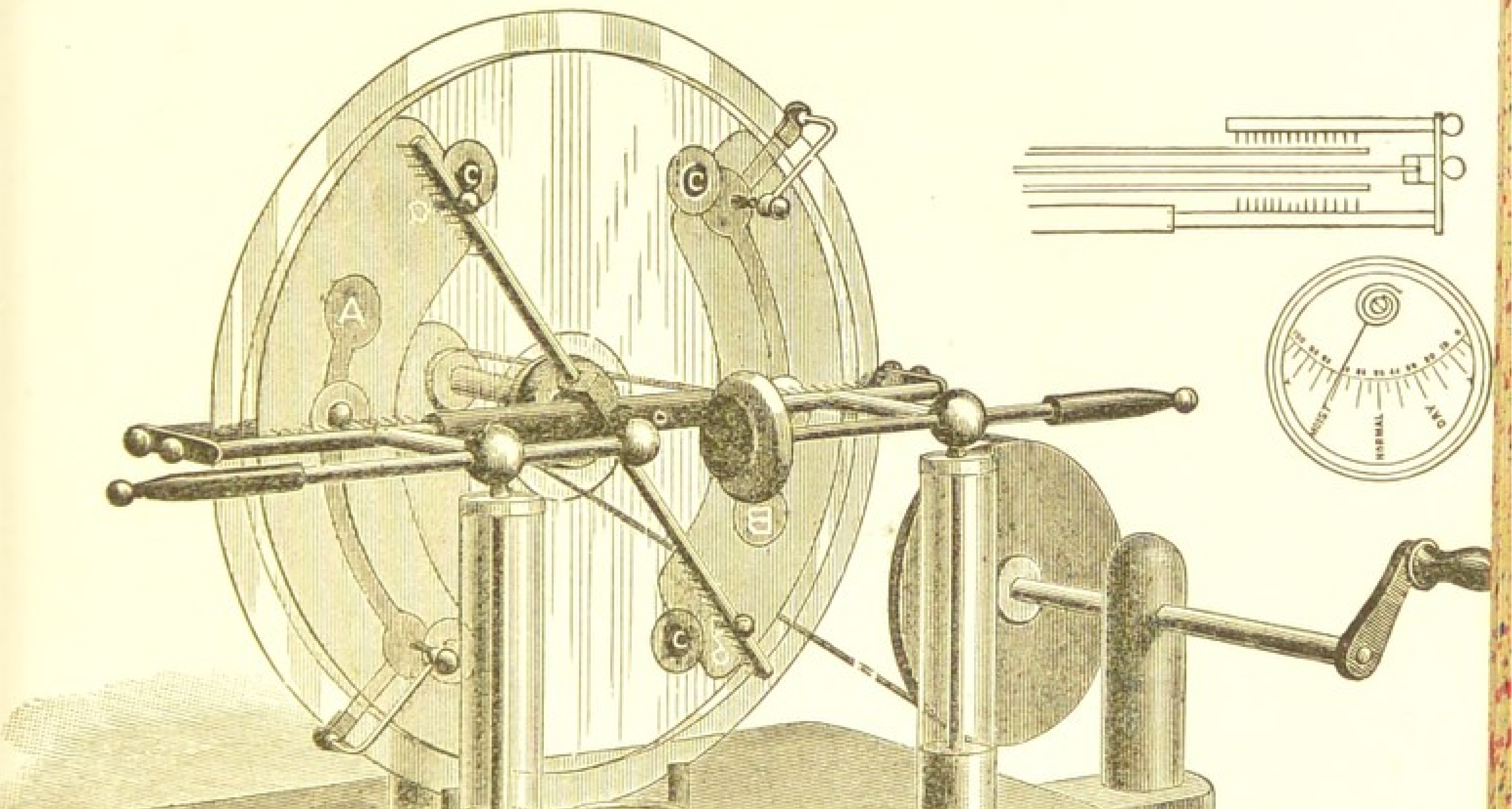

Fig 4—The Modern Töpler Machine.

site directions, and are enclosed between two stationary glass plates firmly set in the frame, which protect the generator from injury, dust, and moisture. The latter seems to be the principal feature which is relied upon to constitute an improvement, and we very much question whether this does not constitute a decided disadvantage rather than an improvement, since a certain amount of dust and moisture is bound to enter through the openings for the belts, and when once there is with difficulty removed,

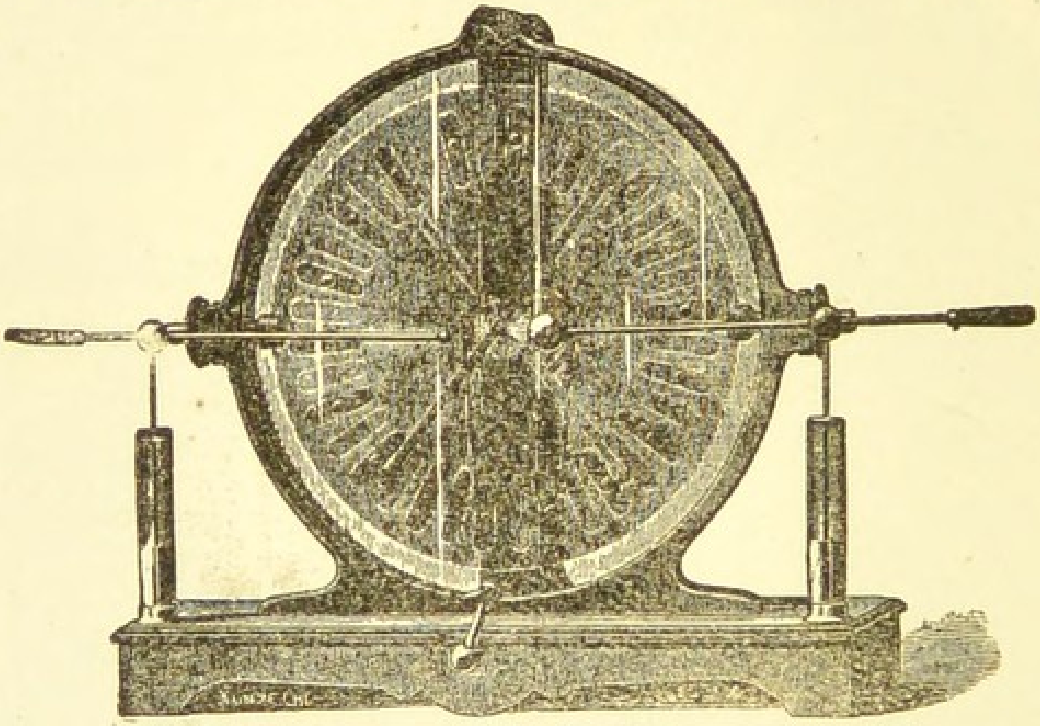

Fig. 5—The Wimhurst Machine.

the whole machine having to be taken apart. It is best to have a covering for the entire machine, which can be quickly and conveniently removed, as in the case of the cabinet shown in Fig. 28.

Although not improved much *electrically*, the Töpler machine has, however, been greatly improved *mechanically*, and in its *adaptation to the requirements of the medical profession*, by Prof. Philip Atkinson, of

Chicago, whose machine, is manufactured by the McIntosh Battery Co. of the same place.*

This machine is admirably constructed mechanically, and after a careful investigation and an extended practical experience, the writer unhesitatingly pronounces it the *cheapest*, and at the same time the *best*, machine upon the market for the purposes of the electro-therapeutist, because:

It is neat and compact, occupying but little space:

It generates as high an electro-motive force as many other forms of machines of from two to four times its size, and which frequently occupy more space that the whole cabinet illustrated in Figs. 27 and 28:

It does not get out of order readily, because of its superior mechanical construction:†

It is provided with a simple, convenient and effective means of tightening the belt when this becomes loose:

Its construction is such that it may be easily and quickly taken apart for cleaning:

---

*To those who wish to make a thorough study of static electricity, the author recommends the reading of Atkinson's book on this subject, published by W. J. Johnston of New York.

† This might be still further improved upon by the substitution of *longer* bearings or journal boxes for the shaft which carries the driving wheel. In ordering, demand this improvement.

It will generate a current *nearly* every day out of the year, when properly cared for, only failing two or three days out of the month, during the two hottest summer months:

It picks up its charge and begins to generate very quickly:

It runs *very* easily and smoothly, requiring but little power:

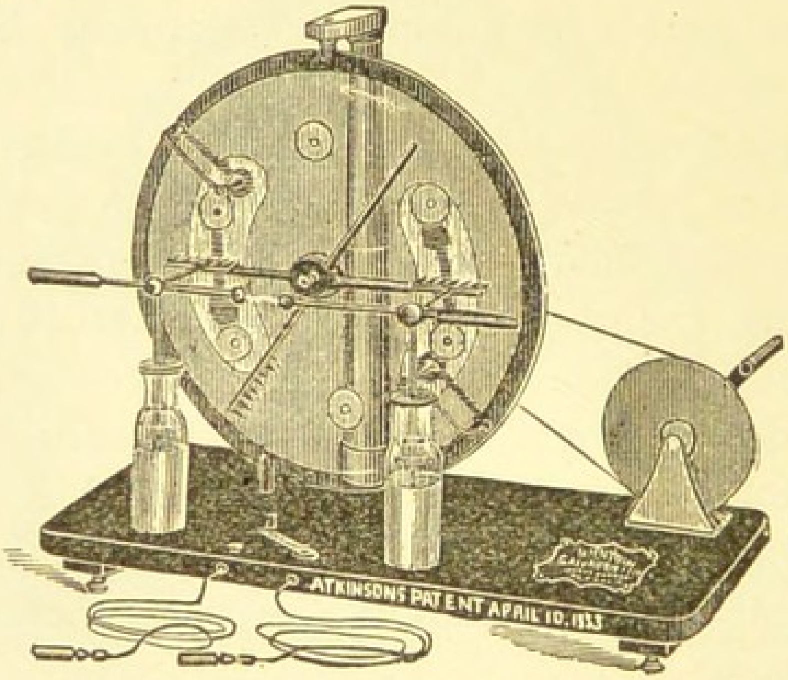

Fig. 6—Atkinson's Improved Töpler Machine.

It is provided with a very superior and convenient method of securing the "*induced*" current, which produces physiological effects similar to the Faradic current:

It will, when in good order, produce a spark equal in length to the radius of the revolving wheel:

It is not so large as to entirely preclude the possibility of its being taken to the bedside; and the future will find this frequently done, for the purpose of facilitating convalescence from low types of fevers, through the superior tonic influence of static electrizations:*

Its peculiar and superior mechanical construction adapt it to be run by either hand or some form of mechanical power, which is not the case with some others.

A static machine is nothing more nor less than a device for dynamically producing what is chemically produced in a Galvanic battery—that is, a *difference of potential.* In the case of the static machine, the difference of potential is very high, (over 60,000 volts) and yet the resulting current is very small, because the internal resistance of the machine is very high, (millions of ohms) while in the case of the Galvanic battery, the difference of potential is comparatively low, (from 1 to 2 volts), but the current large, because the internal resistance is likewise comparatively low (from ½ to 5 ohms). But *so-called*

* It is, however, to be hoped the future will see the development of still more portable and less fragile machines of equal power, that could be as readily carried to the bedside as a Faradic battery, and we see no inherent reason why this should not be capable of accomplishment. The introduction of such a machine should give an unparalleled impetus to the use of high potential currents for therapeutic purposes. It is indeed possible the writer may himself produce such a machine in the near future.

static electricity nevertheless has *volume*, and *flows* just as much as any other form of electricity. The author was the first in *this* country,* so far as he knows, to demonstrate the fact that, if the two combs of a Holtz machine be connected with the poles of a second similar one, which is then set in action, the plate of the first machine will begin to rotate. Here, then, the electricity generated by one machine *flows* to the second machine, and thus transmits the motion of the second to the first machine, the one expending what the other produces. In this experiment, the two machines are connected by *opposite poles*, the system constituting a "*circuit*," which is traversed in a *definite direction* by a *continuous electrical current*. Static electricity, therefore, possesses all of the characteristics of a Galvanic current,—volume and tension; manifesting polarity, with its distinctive effects, flowing in a definite direction, and being either continuous or intermittent. It can decompose water; produce mechanical power; produce physiological, as well as luminous and heating effects; magnetize, iron and steel; produce chemical changes, such as the separation of iodine from the potassium salt in iodide of potassium; and, in fact, do everything that

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*See paper read by the author before the Civil Engineers Club of St. Louis, April 23, 1884. The demonstration was, however, first made in the presence of Prof. Francis E. Nipher, in 1883.

can be done by a Galvanic current,* *only not to the same extent*, because, as explained, the strength or volume of its current is small. On the other hand, however, its pressure is great, so that it may reach organs and parts that could not be reached by the Galvanic current, and hence its small volume will often do more good than the large volume of the Galvanic current which may never reach the seat of trouble; on the same principle that an ounce of powder in the hands of a brave man who will carry it to the seat of war, will prove more effective, than one hundred pounds in the hands of a coward who has not the courage to reach the battle ground.

Currents from static machines may be either *continuous* or *intermittent*, but their volume is of *necessity* very small, and may, therefore, be neglected in all measurements. The pressure or difference of potential, however, is a very important factor which may be varied, and can be measured. The author has designed a novel, direct-reading electrometer, Fig. 7; which will be found to be a very serviceable instrument for this purpose; it should be mounted directly upon one of the poles of the machine. Its use will undoubtedly help to place this branch of electrotherapy upon an advanced and more scientific basis,

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*We expect these statements will prove somewhat dumbfounding to those accustomed to reading current works on electro-therapeutics. But the author is prepared to meet all controversies in the journalistic forum.

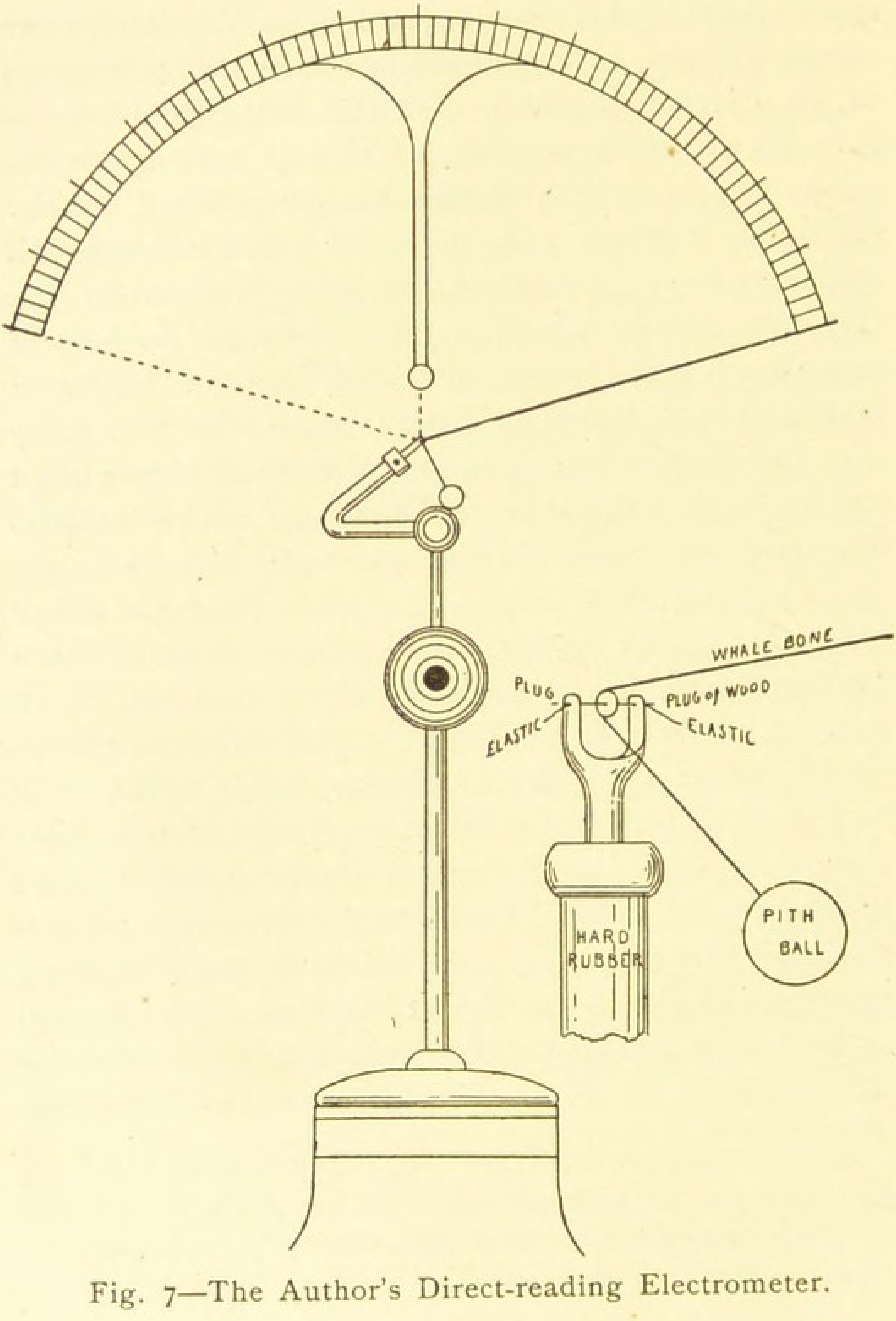

Fig. 7—The Author's Direct-reading Electrometer.

and furnish a means of studying the causes for the capricious action of static machines. The strength or volume of the current produced by these machines is nearly proportional to the velocity of their rotation. The electro-motive force or pressure, however, is independent of the velocity of rotation, (about 53,900 volts at all speeds) but diminishes as moisture increases. The internal resistance dimminishes rapidly with increased velocity of rotation (2810 million ohms at 120 revolutions per minute, and only 646 million at 450 revolutions). The deleterious *effects* of moisture are decreased by spreading beneath the machine a few drops of petroleum. The *presence* of moisture may be largely avoided by the use of a saucer of anhydrous chloride of calcium, or of sulphuric acid, placed in the case with the machine.

In the Atkinson machine, the upper pole to the left, connecting with the inside of the Leyden jars, is the positive one; while the lower pole, to the left in the base, connecting with the outside of the jar, is negative. It will generate only when being revolved in one direction—to the left when facing the front of the machine. It should be insulated from the table on which it stands, by means of inverted glass tumblers coated with shellac. The table supporting the machine should also be insulated from the floor by placing glass telegraphic insulators, coated with shellac, upon the legs. The table should stand as far away from the walls of the room as possible, never nearer than one foot, and should be located in as large a room as possible, preferably in a south room and in front of a south window. When in daily use the machine should be thoroughly cleaned with a silk handkerchief every morning, catching the handkerchief by the ends and passing it back and forth between the plates and over the outside surfaces front and back. Attention to these little details will greatly enhance the generating power of the machine at all times, as well as cause it to be operative the greatest possible number of days out of the year.

The medical uses and methods of applying the currents derived from static machines, will be discussed in another place.

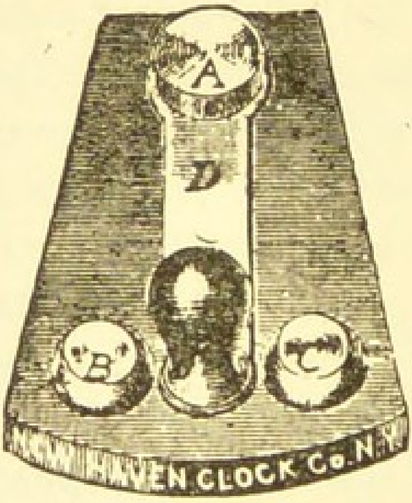

Fig. 8—Two-point Switch.

Switches will give an operator an unparalleled amount of trouble, and cause hidden defects that are sometimes very perplexing and difficult of detection, unless properly constructed in the first place. Each lever (D, Fig. 8) of a switch should have a separate contact spring beneath it, the pressure of which against the contact point can be conveniently adjusted by the physician. The central pin (A, Fig. 8) of the lever should also have an arrangement for tightening from the *outside*. Switches containing these elements are to be found upon the DuBois-Reymond coil manufactured by the Law Telephone Co.* Switches are made with one, two, three or more points, according to the purposes for which they are designed. Fig. 8 shows a two-point switch, mounted upon a hard-rubber base; the current is led in at A and out through the point B or C, according to the position of the lever D. Switches of this character are used in the author's cabinet in the manner diagrammatically shown at 1, 2, 3 and 4 in Fig. 29. In Fig. 29 1 and 4 are three-point switches, 3 is a two-point, and 2 a four-point switch.

Pole-Changers are calculated to give even more trouble than simple switches, when constructed in the ordinary manner shown in Fig. 9. These must likewise be provided with adjustable contact springs beneath the levers, and with means for tightening up

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*The switches shown in Figs. 8 and 9 are devoid of these elements, being introduced for the purpose of showing the difference between properly and improperly constructed ones. A pole-changing switch possessing these elements is, however, shown in Fig. 10, as constructed by Mr. Gaiffe of Paris; a a indicates the adjustable contact spring, and b, the tightening screws for the levers.

the central pins of the levers from the *outside*, so as not to have to remove the entire switch and connections from the table every time a loose contact is observed.

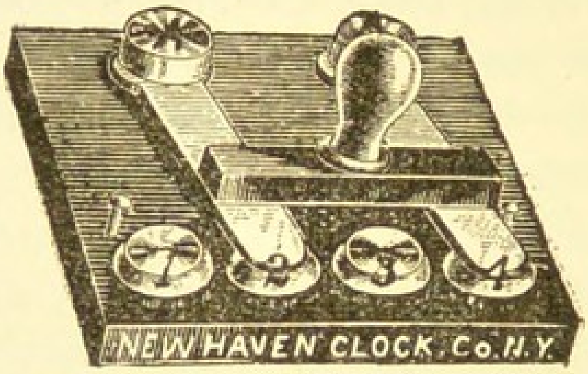


Fig. 9—Pole-Changer.

In this device, the positive and negative poles are connected respectively with A and A, while the contact points 1 and 4 are connected together, and the same with 2 and 3. The point 1 is connected

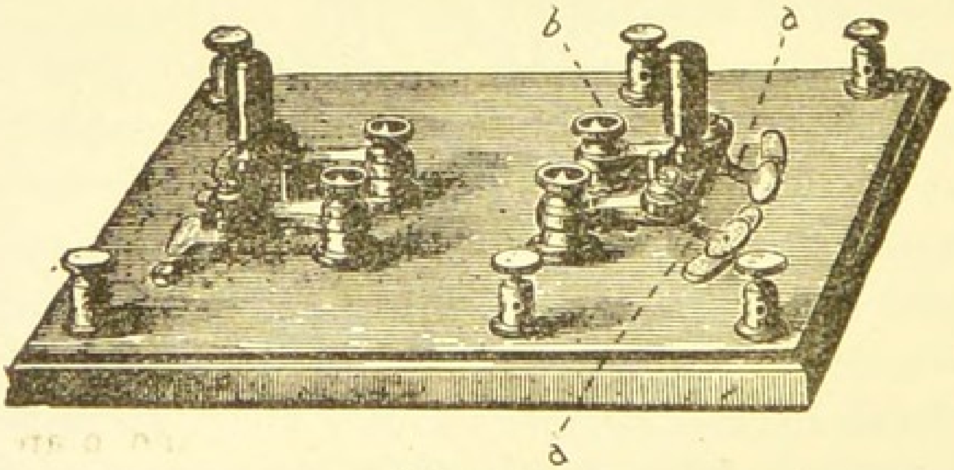


Fig. 10.

with one binding-post, and the point 2 with the other. The movement of these levers from right to left, and left to right, will thus change the poles connected with the binding-posts. These connections are diagrammatically shown at 5 in Fig. 29 and at A B C, in Fig. 11.

THE CURRENT ALTERNATOR, REVERSER AND COMBINER, is made up of two pole-changing switches of the kind just described. It is illustrated in Figs. 10 and 11, the latter giving a diagram of the connec-

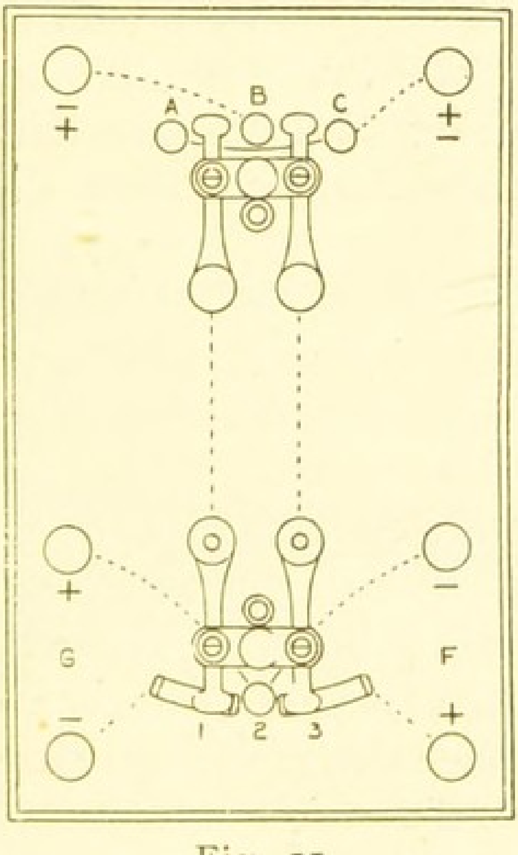


Fig. 11.

tions. Two pairs of posts (G. and F.) receive the wires from the poles of the Galvanic and Faradic batteries respectively. When the springs rest upon 1 and 2, the Galvanic current alone circulates, and when upon 1 and 3, as in the diagram, the Galvanic current passes through the secondary wire of the induction coil, and then through the subject included between the binding posts ± and ±. Thus superimposing the Faradic current upon the Galvanic current, allowing both to be used at one and the same time. With this apparatus, therefore, we may from one pair of binding posts, secure either the Galvanic or Faradic currents, or both currents combined; and we may reverse the direction of either the Galvanic or Faradic, or of both combined. The advantage of being able to pass immediately from the Galvanic to the Faradic current without removing the electrodes is very great, especially in electro diagnosis, whilst the operation of "Galvano-Faradization," which we are thus enabled to practice quickly and conveniently, is one of great therapeutic value. DeWatteville is the author of this idea. Waite & Bartlett, of New York, manufacture such a switch.

An Audible Indicator, to make known through the sense of hearing the fact that the Galvanic circuit is closed and the current flowing, is a very desirable adjunct to an office outfit. It will often save many a dollar, and great delay and annoyance, by making it impossible for an operator to inadvertently leave his battery circuit closed, thus completely polarizing and destroying the battery. It will of course also indicate when a battery is unintentionally closed, through some defective condition of the connections, such as a "*cross*" in the wires.

What electricians call a "*buzzer*" will best serve this purpose. It is operated by a separate cell, the circuit through it being closed by means of a fine wire electro-magnet included in the working or main Galvanic circuit,—see K, Fig. 29 and 14, Fig. 28.

RHEOPHORES OR CONNECTING CORDS, serve to establish electrical connection between the electrodes and the binding-posts of the battery. Only practical experience can give any adequate idea of the petty annoyances, loss of time, and unsatisfactory results, occasioned by the use of poor connecting cords. Those ordinarily sold by instrument-makers are, as a rule,

Fig. 12—Single Conduction Coil made of 16 strands of No. 31 copper wire, with silk braid cover.

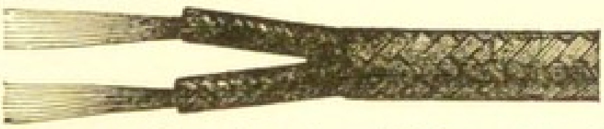
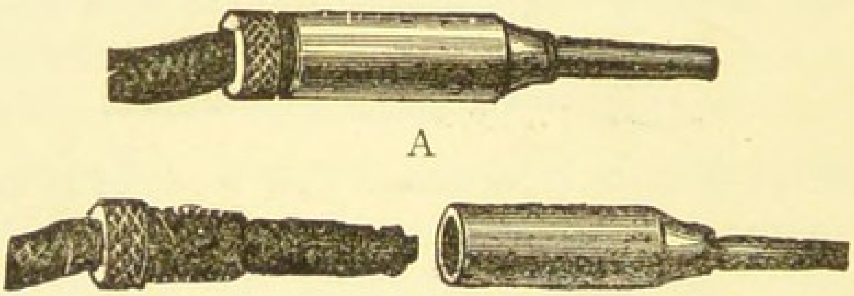


Fig. 13—Double Conduction Coil made of 16 strands of No. 33 copper wire, with silk braid cover.

made of nothing but *tinsel*, and absolutely worthless. The best material for this purpose will be found to be the double, flexible, suspension cords, used in connection with incandescent electric lighting. These cords are made up of a number of strands of No. 30 copper wire, covered first with rubber, and then with silk. They cost but ten cents per yard, and two yards will make a pair of cords of the same length, since they are double. It is best to have cords of different colors for the two poles. Figs. 12 and 13 illustrate properly constructed cords, as manufactured by the New Haven Clock Co., the former a single and the latter a double conductor cord. Waite and Bartlett, of New York, also make an excellent cord. It is often necessary to have a double or bifurcated cord, which will allow of two electrodes being attached to one pole, to diminish the local action of the negative pole, or to touch upon two points at the same time, or for purposes of electro-diagnosis.



A

B Fig. 14. C

RHEOPHORE-TIPS, are also frequently the source of unsatisfactory results and experiences in the use of electricity. They should never be fastened to the cord by a simple winding of the wire around the tip, but should either be soldered to the wire of the rheophore, or fastened to it by means of a screw. The best tips upon the market up to the present, are manufactured by the McIntosh Co.,—see Fig. 14. These are adjustable, enabling the operator to repair the cords when broken or to transfer the tips to other cords without the delay of sending them to the shop. A shows one adjusted for use, and B and C, the separate parts ready for attachment to a new cord, or to a different part of an old one. This tip, however, might be considerably improved upon by slitting up the threaded portion of B, so that the wires may be brought through this slot and wound around the base of B. Then when B is screwed into C, the wires of the conductor will be firmly clamped between B and C, thus insuring good metallic contact between the tip and the rheophore. The writer has made this improvement upon his own tips, and finds it an admirable one.

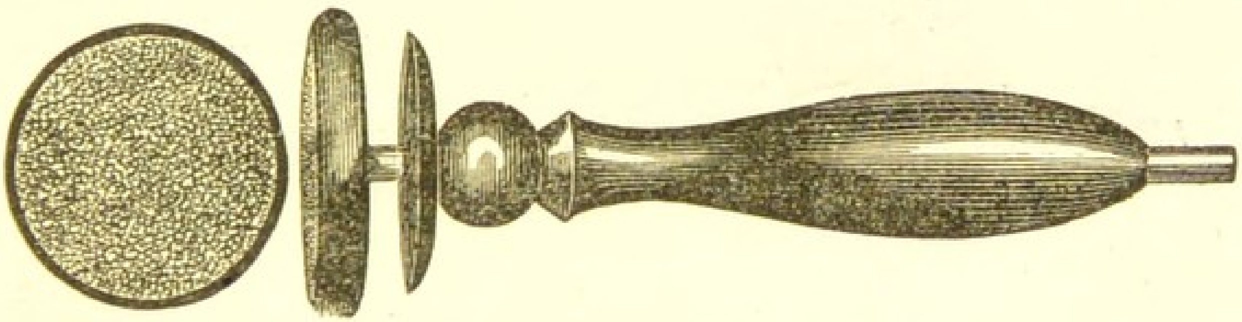


Fig. 15.—Plain Electrode-Handle, with carbon electrode attached.

Electrode Handles, may be either *plain*, *interrupting*, *pole-changing* or *rheostatic*. The *plain* handle (see Fig. 15), should be about three inches long and one inch in diameter, being hollowed out about the middle to facilitate the holding of two in one hand, one between the first and second, and the other between the third and fourth, fingers. This handle and method will be suitable for local Faradizations of muscles. The *interrupting* handle is provided with a switch for conveniently making and breaking the circuit, and is indispensable for electro-therapeutic and diagnostic purposes. The pole-changing handle is provided with a pole-changing switch, and is very useful in applying alternating Galvanic and Faradic * currents and in electro-diagnosis. The *rheostatic* handle has a compact rheostat mounted upon it, by means of which the operator can with one finger quickly change the strength or volume of the current, even though both hands are occupied in holding the two electrodes. It is very useful

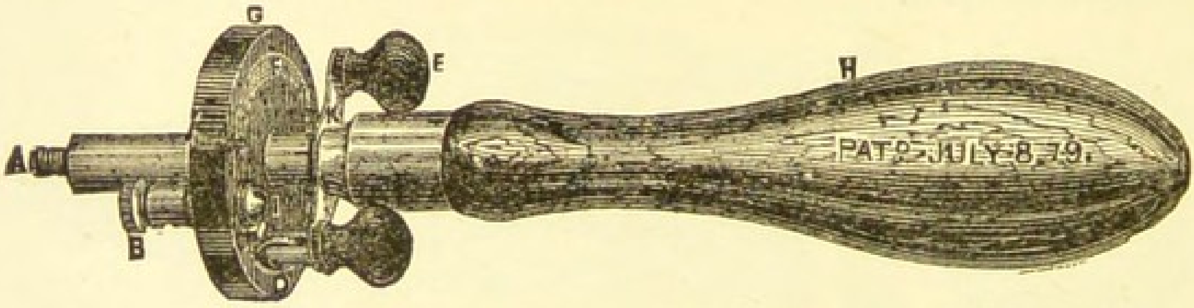


Fig. 16.—Butler's Rheostatic Electrode-Handle, one-half actual size.

when dealing with sensitive parts, or with the organs of special sense, and in diagnostic work. The only handle of this kind known to the author is shown in Fig. 16. The simple movement of E

* We have already pointed out the fact that the effective Faradic current always flows in one direction, notwithstanding the fact that it is, physically speaking, a to-and-fro current.

The plain electrode-handle shown in Fig. 15, is manufactured by the McIntosh Co., of Chicago.

The Butler rheostatic-handle shown in Fig. 16, is manufactured by John Reynders & Co., of New York.

around the handle throws in or out a plumbago resistance, which accordingly decreases or increases the volume of the current.

Binding-Posts, are devices mounted upon batteries and the various instruments, for the purpose of affording a ready and effective means of connecting

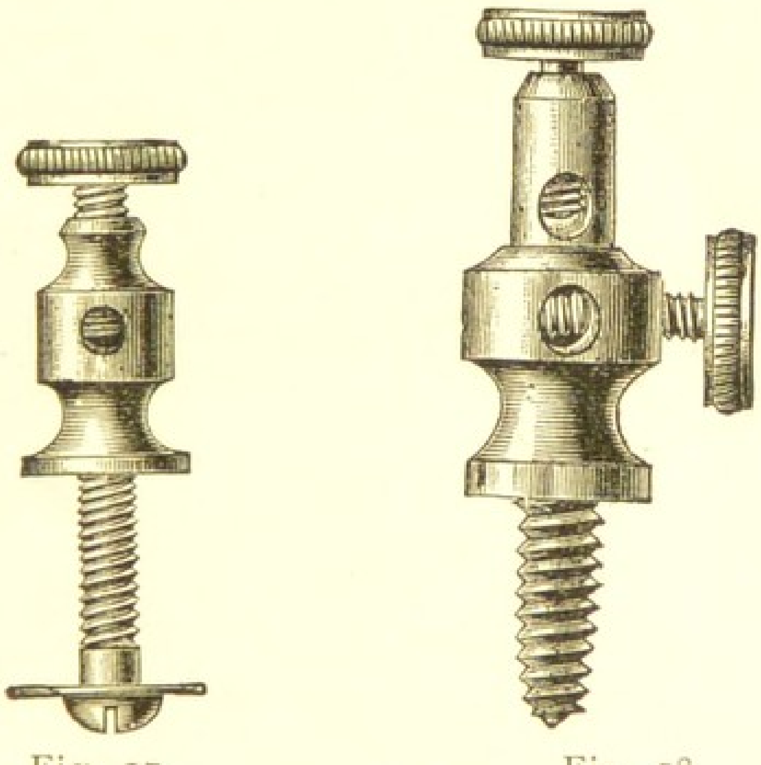


Fig. 17. Fig. 18.

Binding-Posts.

the latter with each other and with the electrophores. Many forms have been devised, the two leading ones being shown in Figs. 17 and 18. The latter, however, will prove most serviceable for electro-medical purposes, the two holes for connections being very useful, inasmuch as it is frequently desirable to be able to make a second connection without having to remove the permanent connection which may have been made in the principal hole. These posts are suited to all forms of tips. These may appear to be small points, but they are very practical and useful ones.

Electrodes, are devices for applying electricity to the body. Too little attention has in the past been paid to the subject of the modifying influences exerted by electrodes of varying sizes and composition upon the strength of the current, and the polar, and inter-polar effects of the latter upon organic tissues. Currents of the same strength will produce widely different polar and inter-polar effects, when applied by means of different sized electrodes. The surface area of an electrode determines what is called the *density* of the current. Dry and wet electrodes produce widely different effects, both polar and inter-polar. The wet electrode produces less local irritation and carries the current beneath the skin to the deeper tissues; while the dry electrode produces more local irritation and aids in confining the current to the skin.

Electrodes are best made either of carbon (see Fig. 15) or lead. If a dry electrode is to be used, carbon is preferable; if a flexible one is desired to accommodate itself to surface inequalities, a thin sheet-lead one is to be preferred. Neither of these substances are subject to either electrolytic or chemical action, and either may be used covered or uncovered; if they are to be covered, absorbent cotton, as first suggested by Dr. Massey, will be the most cleanly and best, using a fresh piece for each electrization. Use pure warm water to moisten the cotton—never salt water, because the salt will cause an endless amount of subsequent trouble, and prove more irritating to the cuticle. Standard sizes, as suggested by Erb, should be employed. These are as follows:

(1) Fine electrode.—½ centimetre ($\frac{1}{5}$ of an inch) in diameter:

(2) Small electrode.—2 centimetres (¾ of an inch) in diameter:

(3) Medium electrode.—5 centimetres (2 inches) square:

(4) Large electrode.—6 x 12 centimetres (2½ x 5 inches):

(5) Very large electrode.—8 x 16 centimetres (about 1¼ x 6½ inches).

Each of these should have the area of the contact-surface in square centimetres stamped upon the stem of the electrode. This outfit will suffice for all ordinary per-cutaneous applications in dermatological, myological, and neurological work.

As a dispersing and indifferent electrode in all heavy electrolytic work, as in gynæcological practice, extra large circular electrodes made of sculptor's clay (the Apostoli abdominal electrode), or of sheet-lead covered with spongio-pilen,* should be used. These should vary from 6 to 12 inches in diameter.

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* An excellent electrode of this character is made by the McIntosh Co., of Chicago. It is 8½ inches in diameter.

Another form, used by the writer, may be made in the shape of a long strip to completely encircle the body, having a width of about 6 inches, and a length of 32 inches. This form is passed around the body and clasped together at the sides by means of elastic bands thrown around four lugs attached to the extremities of the electrode. This latter form is very useful in very sensitive cases requiring very strong currents, when it is not necessary to confine and localize the inter-polar path of the current.

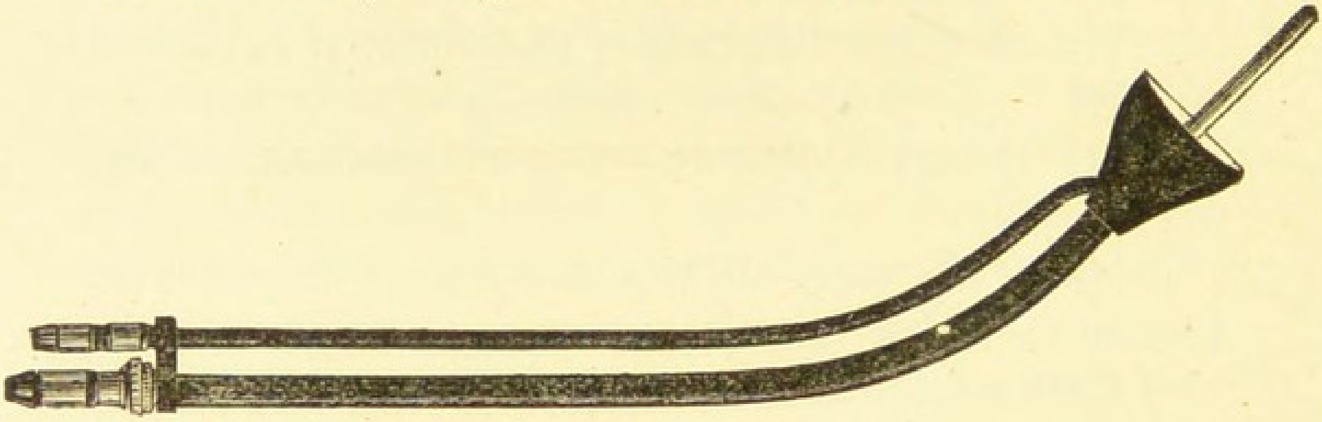

Fig. 19.—Bi-polar Uterine Electrode. The current passes from the cup through the *cervix uteri* to the stem or pin in the centre of the cup. For either Galvanic, Faradic or induced Static currents.

Aside from these, a set of special electrodes of various forms will be required for the effective use of the active pole in the local treatment of the various parts and organs of the body, such as the eye, ear, nose, tonsils, larynx, uterus, vagina, rectum, urethra, bladder, etc.

The best designed and constructed electrodes of this character have been placed upon the market by the McIntosh Battery Co., of Chicago, and the Waite & Bartlett Co., of New York.

A few of these, such as would prove most useful

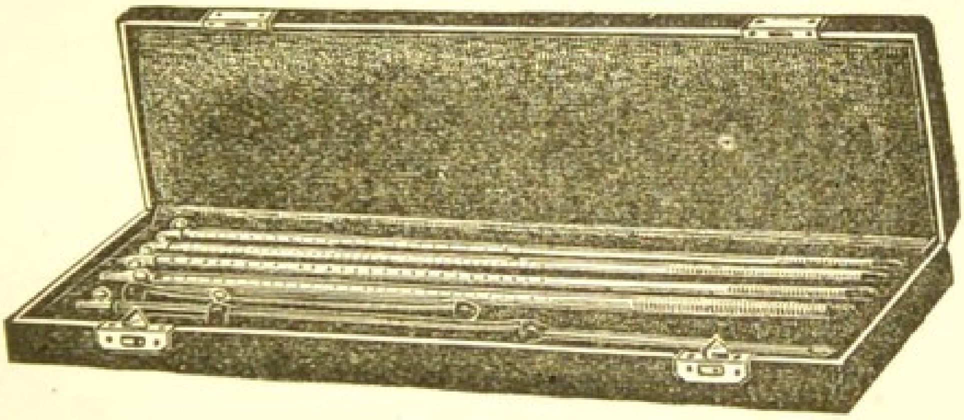

Fig. 20.—Martin's Intra-Uterine Electrodes. These are flexible concentrating electrodes with a definite area of active surface, being designed to carry out the Apostoli treatment. The area of the active surface is stamped on each.

to the general practitioner, are illustrated in Figs. 19 to 25; only such as have been used by the writer

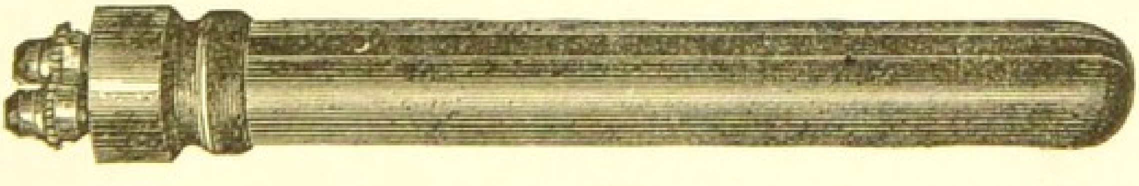

Fig. 21.—Bi-polar Vaginal Electrode with longitudinal division. For either Galvanic or Faradic currents; may also be used as a uni-polar electrode by connecting with a bifurcated cord.

and can be endorsed are here shown. Those which may be readily dispensed with have not been illustrated—for instance, the bi-polar uterine electrode

(Fig. 19) may serve also as a uni-polar electrode, by connecting with but one post, the circuit being com-

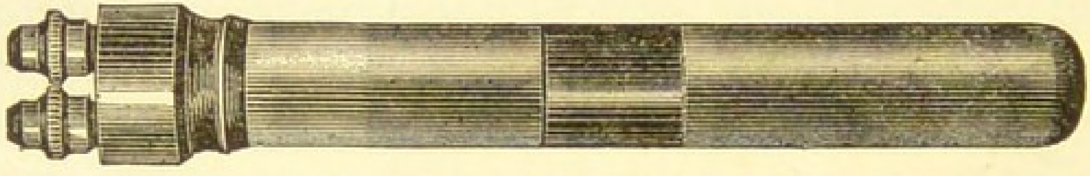

Fig. 22.—Bi-polar Vaginal Electrode with transverse division, may also be used as a uni-polar electrode, confining the current to either end of the vagina.

pleted through an indifferent cutaneous electrode, therefore a uni-polar electrode is unnecessary and hence not illustrated.

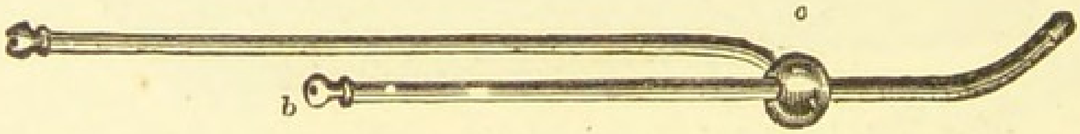

Fig. 23.—Reynder's Bi-polar Uterine Electrode. Adjustable so as to regulate the depth to which the intra-uterine portion enters.

The author's electrode case containing a choice selection of electrodes is illustrated in Fig. 25.

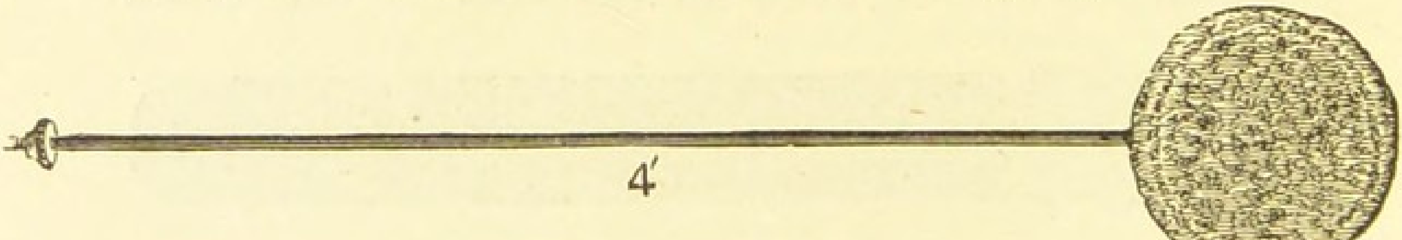

Fig. 24.—Spinal Electrode. Designed to make applications to the spine, and other portions of the body without having to remove the clothing.

Having now described in detail the separate pieces of apparatus essential for a complete *office* outfit, we must consider the assemblage and electric connections of all these several pieces of electrical apparatus into one grand piece known as:—

THE ELECTRO-THERAPEUTIC CABINET. — The writer has devoted a great deal of time and spent

Fig. 25.—Hardeway's Irido-platinum Needle and Holder for the electrolytic destruction of hair follicles.

considerable money in developing what he believes to be the most complete and conveniently arranged electro-therapeutic cabinet ever constructed. Many

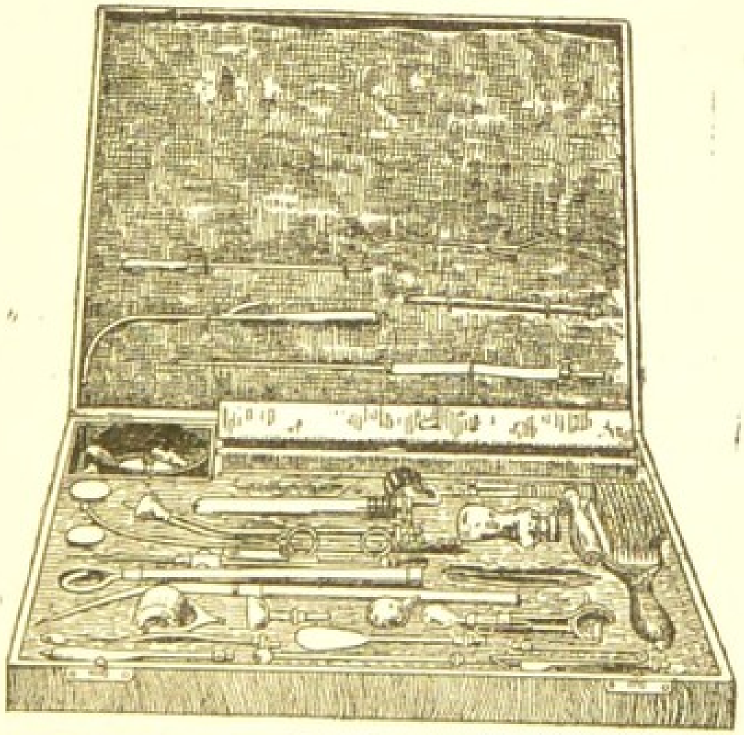

Fig. 26.—Author's Electrode Case.

such cabinets have in the past been designed, but as a rule they have only proved useful as elaborate pieces of office furniture for the mental impression of patients. They have been cumbersome, inconvenient, incomplete affairs, glutted with showy but useless apparatus. In most instances these have been designed by commercial electro-mechanics without any knowledge of, or regard for, the requirements of the practical and scientific electrologist. The catalogues of the various dealers and makers always speak of them as making "showy pieces of office furniture," and that is truthfully about all that can be said in commendation of them. They generally wind up in some second-hand store or junk-shop. The complicated and absurd "*cell-selector*" is nearly always to be found in them, and the Faradic apparatus as a rule, is worthless, except to those who use electricity for the production of "*shocks*," after the manner of the street "fakir." The *so-called* measuring instrument forming a part thereof, is generally nothing but a one or two dollar pocket Galvanometer, that is absolutely worthless as an accurate measuring instrument. The most important part of all, the electrical connections and arrangement of instruments, are made without any regard to the requirements of the practical operator in electro-therapy, electro-biology and electro-pathology. The static apparatus generally fills up one cabinet that will occupy nearly the whole side of an office; while the Galvanic and Faradic apparatus fills up another and separate cabinet of equal dimensions that will occupy the other side of the office. The static machine is generally confined permanently in a case that carries off the current and thus prevents the successful operation of the machine.

The Author's cabinet is shown in Figs. 27 and 28. It is very compact, occupying a floor space of but 34x24 inches, and only 60 inches in height. The

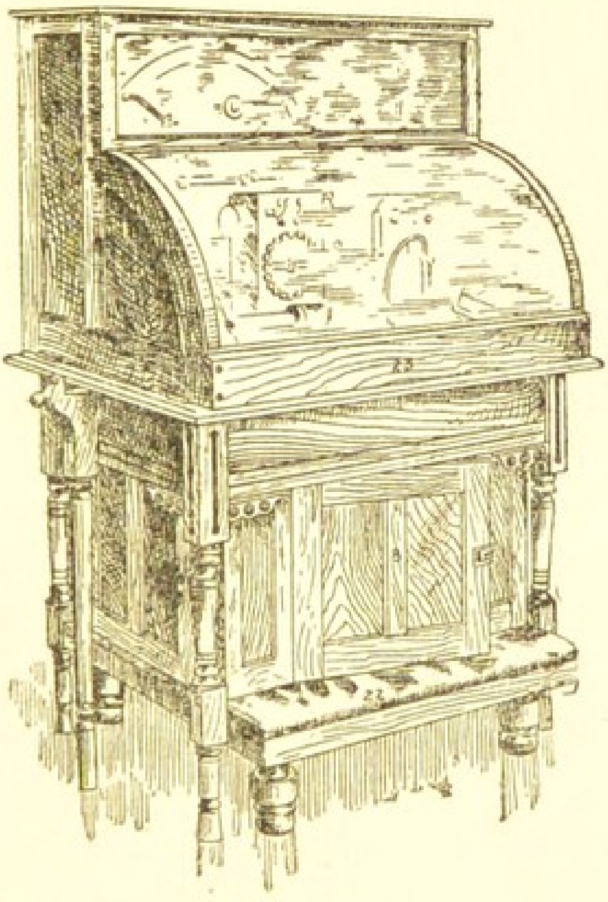

Fig. 27—Author's Electro-Therapeutic Cabinet, Closed.

lower enclosed portion, which is but 27 inches in height, contains the battery cells, of which there are 90, of the Law type, arranged in three tiers of 30 each. Each tier is arranged in a sliding tray that may be readily withdrawn for occasional inspection without making a single disconnection. The upper portion, which is enclosed by a hinged glass-case with a curved front, contains the static machine and an electric motor for driving it, with all the

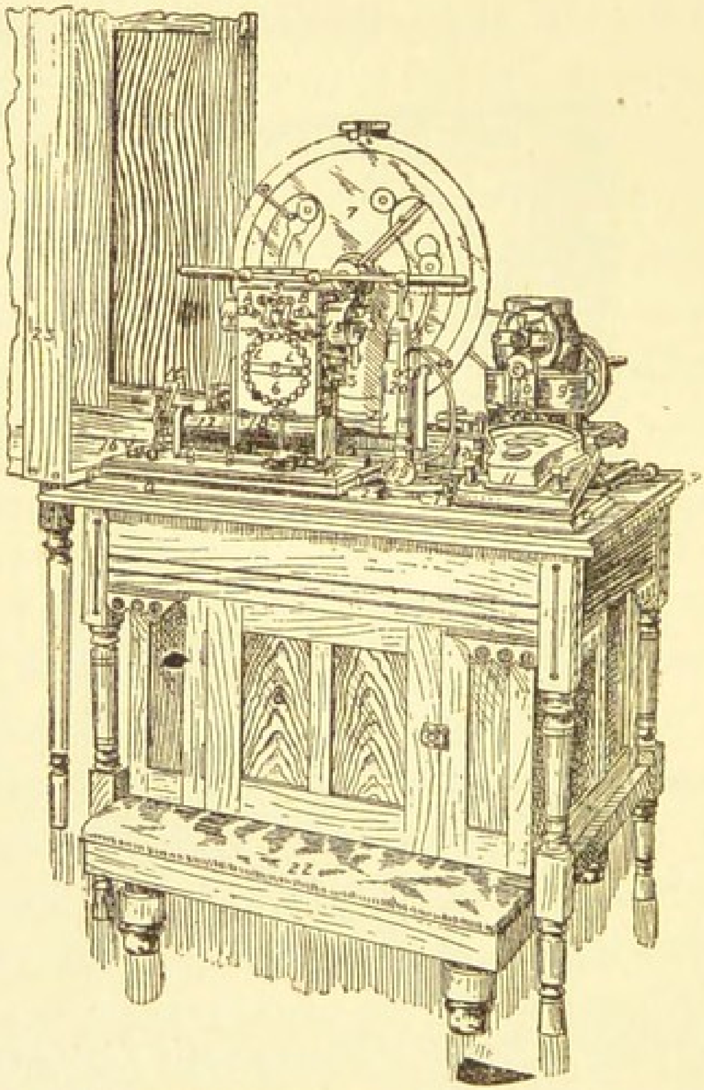

Fig. 28—The Author's Electro-Therapeutic Cabinet, Open

1 Am-Meter Switch.
2 Coulombmeter Switch.
3 Rheotome Switch.
5 Pole Changer.
A and B Principal Binding-Posts
6 Resistance-Box.

7 Static Machine.
8 Enclosure for Battery—Open front and back.
9 Motor.
10 Motor Switch.
11 Am-Meter.
12 Resistance Box for converting Am-Meter into Volt-Meter.
13 Rheotome.
14 Audible Indicator for Galvanic Circuit.
15 Slow Interrupter of Faradic Coil.
16 Opening and Closing Switch for Primary Circuit of Induction Coil.
17 Primary Coil of Faradic Battery.
18 Secondary Coil of Faradic Battery.
19 Current Controller.
20 Coulombmeter.
21 One of the Leyden Jars of the Static Machine.
22 Insulating Platform.
23 Cover.

necessary switches and connections self-contained; the large Du Bois-Reymond Faradic coil, with slow and fast interrupter; the Faradometer; the coulombmeter; the milli-ampere meter; the volt-meter; the current-controllor; the box of standard resistances; the pole-changer, alternator and combiner; the adjustable registering rheatome; the electrometer; the audible indicator, and all necessary switches; the whole being in such electrical connection, one with the other, that any one, or any number, or the whole, according to the desire of the operator, may be thrown into their proper relations with the entire circuit for the proper performance of their respective duties, by the simple movement of a switch, without having to make any changes in the connections, or any disconnections. With this cabinet, the operator may secure from one pair of binding-posts, either the Faradic, the Galvanic, the cautery, the illuminating, or the motive-power current. When not in use, the whole is enclosed under lock and key, without a single connection with the outside, secure from meddlesome children and servants, and thoroughly protected from the dust, moisture, carbon and corrosive gases of the atmosphere. When in use, the air-tight case is thrown out of the way, exposing all of the apparatus freely, so as to render all parts readily accessible for inspection and cleaning, and thus also *removing all surrounding conducting material from the static machine, the presence of which would be calculated to carry off the current as fast as generated.* Fig. 29 gives a diagrammatic illustration of the circuit connections and "*wiring*" for this cabinet. This wiring is placed upon the under surface of a separate board (*a*, Fig. 28), upon which is mounted all of the apparatus enumerated. These connections are permanently made and sealed up, never to be disturbed after being once made. The physician has to do with but *two* wires; these come from the battery, and are connected to two binding-posts upon the board carrying the apparatus. In Figs. 28 and 29, corresponding parts are similarly lettered. In Fig. 29, 5 represents the pole-changing switch, which in the position here shown makes the binding-post A positive, and post B negative; I is the ammeter switch, and when its lever, L, is in position I, the ammeter is "*short-circuited*," or thrown out of circuit; when in position II, it is arranged for reading from the black or large current scale; when in position III, it is arranged for reading from the red or small current scale;—2 is the coulombmeter switch, and when its lever, L, is in position I, it is "*short-circuited*" (not included in the circuit, or out of use); and when in position II, it is arranged to throw in the shunt *s*, which makes it read up to 200 coulombs, and decreases its resistance; and when in position III, it is arranged to read up to 10 coulombs only;—3 represents the rheatome switch, and when its lever, L, is on 0, it is "short-circuited" and inoperative in either the Galvanic or Faradic circuit; when in positions I, II, and III, however, it is operative, giving different numbers of interruptions per minute in the several positions, being thrown into either the Galvanic or Faradic circuit by means of the switch 3^a, which, when in position I, places the rheatome in the Galvanic circuit, and when in position II places it in the Faradic circuit, the contact screw being screwed down tight upon the rapid vibrator of the induction coil; 4 represents the switch for throwing in and out the volt-meter, when its lever, L, is in position I, the resistance which converts the ammeter into a volt-meter is "short-circuited," so that the instrument reads simply as an am-meter; but when the lever is in position II, the 10,000 ohm resistance coil is in circuit, and the instrument reads to 100 volts, as shown in the diagram, it being in position to read the difference of potential across the battery, while when the lever is in position

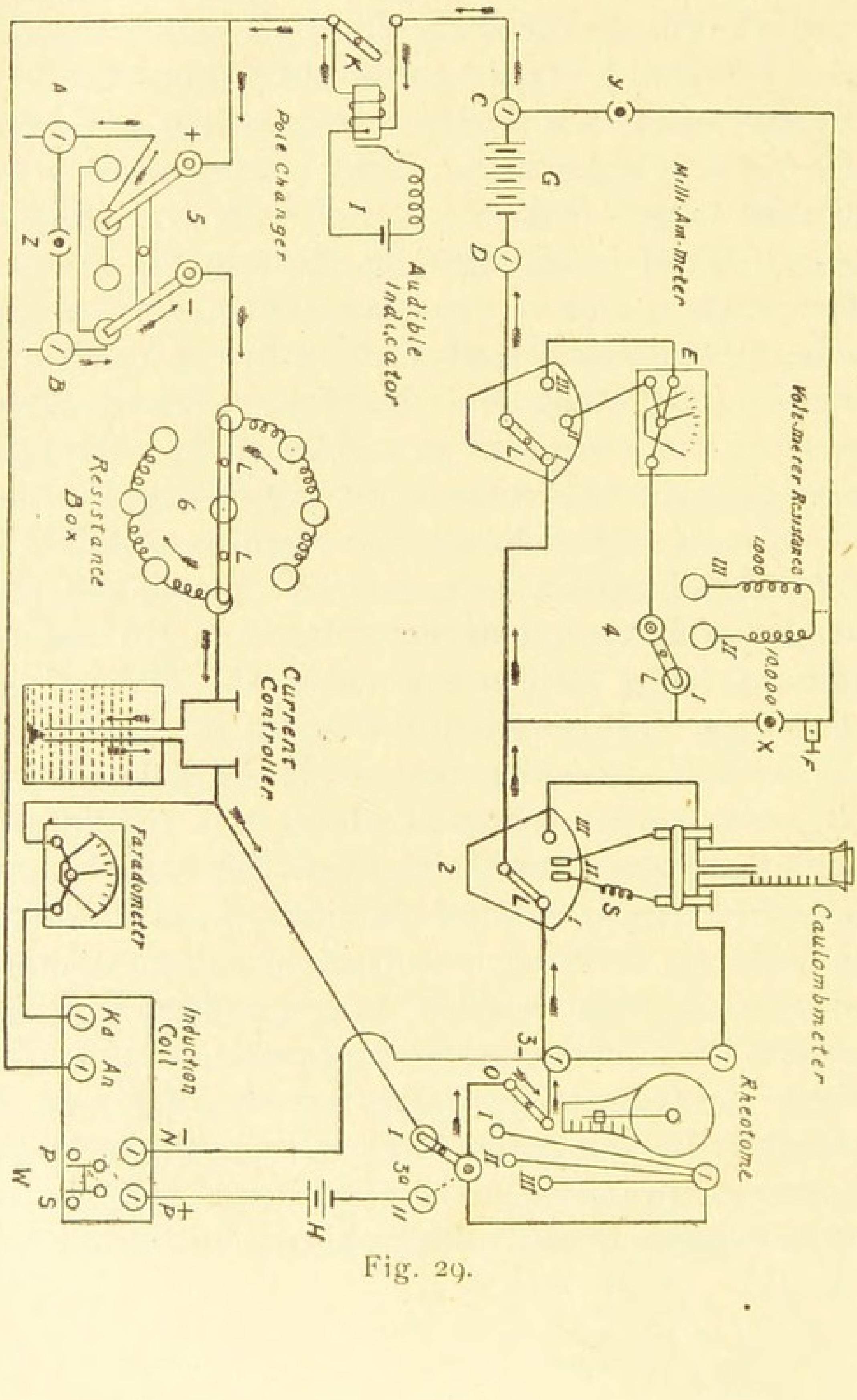

Fig. 29.

III, it reads only to 10 volts, assuming all this while that the lever L of switch 1 is in position III; 6 represents the resistance-box, and when its levers L L are in the position shown, all the resistance is cut out, but when moved in the direction of the arrows, the resistance is gradually inserted until the required number of ohms have been introduced; G represents the battery of cells for Galvanic work; H, the cell for induction coil; I, the cell for the audible indicator; N, P, the ends of the primary wire of the induction coil; Ka, An, the ends of the secondary wire of the induction coil; A, B, the principal binding posts, from which all currents are obtained; C, D, the binding posts for receiving the two wires from the principal battery; K, an electro-magnet to close the audible indicator circuit whenever the smallest amount of current flows through the main circuit; Z is a plug-hole for short-circuiting A and B; W is a switch for throwing in either the primary or secondary wire of the induction coil; X, a plug for connecting and disconnecting the volt-meter from the main circuit, so that it may at any time be rendered independent for separate use. The connections are such that any of these pieces of apparatus may be conveniently removed from the cabinet in an instant, and used for out-side practice, which is a very desirable feature, rendering but one set of apparatus necessary for office and out-side practice. Beneath the lower closed portion of the cabinet there is a space for an insulating platform to stand, which may be removed by the foot of the operator whenever static electrizations are to be given. Thus located, this platform is always out of the way of everything when not in use, and yet easily accessible whenever required.

The writer will be pleased to supervise the preparation of such a cabinet and outfit for any physician requiring the same.

A SERIES OF EXPERIMENTS WITH THE CABINET, in illustration of its usefulness, will now be given:

1st. *For a Simple Administration of Continuous Galvanism.*—Connect the electrodes by means of the electrophores to the binding posts A and B; now place the lever L of switch No. 1 in position III, leaving all other switches in the position shown in the diagram; now place the electrode surfaces upon any desired portion of the body; observe the ammeter, and it will be seen that no current yet flows, but now gradually turn the screw-head of the current controller so as to lower the plates of carbon into the water; the ammeter will soon indicate the presence of a current. When the indicator has moved up to the figure 10 on the red scale, which is as high as this scale reads, stop lowering the plates of the current controller, and turn the lever L of switch 1 to position II; the indicator will now come back to the second division of the scale, and thus indicate 10 milli-amperes on the black scale, and the indicator could now continue up to the 500 mark, providing we continue to lower the controller, but the pain from the current prohibits our going much further, so we will stop here. Now observing the coulombmeter, we find it to be inactive; but now move the lever L of switch 2 into position III, and little bubbles of gas immediately begin to travel upwards through the water, pressing the inner column of water down, until finally it reaches the figure 2. We have now passed two coulombs of a ten milli-ampere continuous Galvanic current through the tissues included between the points of contact of our electrodes; or, in other words, we have used a continuous Galvanic current having a strength of 10 milli-amperes for a period of 3 minutes and 20 seconds.* Suppose we now wish to measure the resistance of the tissues that have been included between the electrodes. We simply cut the coulombmeter out by replacing lever L of switch 2 to its original position, and now turn the levers L L of switch 6, in the direction of the arrows, until we have included all our resistance; next we remove the electrodes and place a plug in Z, thus connecting A. B. directly; we now gradually withdraw the resistance by moving the levers L L in the opposite direction until the indicator of the ammeter again stands at 10. The amount of resistance now left in, which may be read off

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*To change the polarity of the electrodes, we have only to move switch 5 to the right or left, according as we wish to make A or B positive.

directly by observing the position of L L 6, will indicate the resistance of the tissues, plus the resistance of our circuit. The latter is now measured by replacing L L 6 to their original position, as shown in diagram, thus taking out all of the resistance coils observing the reading of the ammeter, and then reintroducing resistance until a current of one-half the strength is indicated. The resistance now included will be equal to the resistance of our circuit, and if this be now subtracted from the first finding, we shall have the exact resistance of the tissues or body upon which we have been operating. Multiplying this resistance by the current strength (which was ten) and dividing by 1000 because a milli-ampere is one-thousandth part of one ampere, we *should* have the difference of potential in volts across the points of contact of the electrodes. To prove this and then see if our measurements and calculations have been correct, place the electrodes as before, and connect one end of a second pair of electrophores with them; connect the other ends of these with binding-posts F and E, and remove the plug X, the switch L4 being in position II; the volt-meter will now indicate the difference of potential in volts across the electrodes, and if this is equal to the product of the resistance multiplied into the strength of the current, then we know that there has been no error and that our observations and calculations are correct.

Suppose that in applying the current in the first instance, we kept lowering the controller more and more until it was completely lowered, and yet the proper amount of current did not appear from the indications of the ammeter. This would indicate either an excessive amount of resistance somewhere in our circuit, or, a deficient electro-motive force in our battery, and the question now arises, how shall we locate or differentiate the trouble. We have only to place L 1 in position III, and L 4 in position II, and push plug X into Y; our volt-meter will now indicate the electro-motive force of the battery in volts, and if this is at least equal to one volt per cell, we may be certain the battery is all right and that the trouble is in the resistance of our circuit, which we must then proceed to measure, first in entirety, then in sections, in the manner already described.

2nd.—*To Administer the Intermittent Direct Galvanic Gurrent.*—Place same electrodes as before, see that plug Z is removed, place LI in position II, and allow all other switches to remain as shown in diagram; now gradually turn the current controller until the desired strength of current is obtained, then move L 3 from 0 to the proper position to give the required number of interruptions per minute, in the meantime watching the ammeter and regulating the current with the controller; when the mean throw of the needle indicates the desired strength of current, cut out the ammeter by moving switch L1 to position I; we now have a direct intermittent Galvanic current of any desired character.

3rd.—*To Secure an Illuminating Current.*—Cut out all measuring instruments, the audible indicator magnet K, and all other resistances, except that of the current controller; next connect a double electrophore as shown in Fig. 13 to the binding-posts A and B, connecting the other ends of the cord to the incandescent lamp it is desired to operate, and gradually lower the current controller. We will now have a current that will operate any incandescent electric lamp from ½ to 16 candle-power; a 3 candle lamp being, however, the one generally used in illuminating instruments. The yellow-white point of incandescence should never be passed. A blue-white light means death to the lamp.

4th.—*To Secure a Motive Power Current* to operate the electric motor for running the static machine: The motor is supposed to be a 110 volt shunt wound machine, requiring a current of but $\frac{1}{10}$ of an ampere and giving about $\frac{1}{16}$ of a horse-power. Cut out all resistance and measuring instruments as before, turn on the motor switch upon the motor, and now gradually lower the current controller. The motor will now soon begin to revolve.

5th.—*To Secure an Alternating Galvanic Current.*—Arrange things as in the first experiment and place the electrodes; now move the switch 5 backwards and forwards, after first turning on the required strength of current. We thus secure an alternating Galvanic current of any desired strength.

To Get a Simple Secondary Faradic Current with Rapid Interruptions.—See that all the switches are as shown in the diagram, with the exception of switch 3A which is to be turned into position II, and switch W, which is to be turned to position S, which gives the secondary current. Now see that the secondary coil is removed from over the primary one. Next place the electrodes in position, after having connected them with A and B, and proceded to lower the controller. Observe the Faradometer, and if, after completely lowering the controller, the current has not reached the desired strength, then proceed to move the secondary coil further over the primary one, until the desired current is indicated by the Faradometer. Should we now wish a lower electro-motive force or a current from the primary coil, we have only to raise the controller, move the secondary coil completely over the primary one, and then shift switch W to the left. Now proceed as before, first lowering the controller and then gradually moving the secondary coil from over the primary one. To change the polarity of the electrodes, shift switch 5. To produce any required definite number of intermissions to the rapidly interrupted Faradic current, turn the lever L of switch 3 to the proper position, and start the vibrator. To produce a series of rythmical induced impulses, it being required to know the number per minute, screw down the contact screw tight upon the rapid vibrator of the coil, and adjust the rheotome as desired, and the required current will be produced.

7th.—*To Measure the Resistance of any Outside Piece of Apparatus.*—Connect the object to be measured to the binding posts A and B, and proceed as described when speaking of the measurement of the resistance of tissues.

8th.—*To Measure the Electro-Motive Force of Any Outside Source of Electrical Supply*, or the difference of potential across any outside object.—Connect the object with posts D and F, see that the plug is removed from both X and Y, and then proceed to move switches L1 and 4 to their proper positions according to the character of the potential to be measured.

It is utterly impossible in this small book to begin to tell what can be done with such a cabinet. The author only hopes his efforts in this direction will not be ridiculed as ultra-scientific by those who, through insufficient information, fail to appreciate their value.

MOTIVE POWER for driving the static machine, operating surgical saws, trephines and drills, shown in Figs. 30 to 34, and the air-pump used in compressing air for medicated sprays in eye, ear, nose, and throat work, will be best supplied by an electric motor. It will prove more convenient, more cleanly, and more economical than any other form of power, providing a good type and make of motor is secured. A poor motor will prove a source of much annoyance. All things considered, electrical and mechanical construction, efficiency, convenience of starting, stopping and regulating speed, the Crocker-Wheeler motor will be found to be the best type and make upon the market at the present time, and there is not much prospect of its being very greatly improved upon in

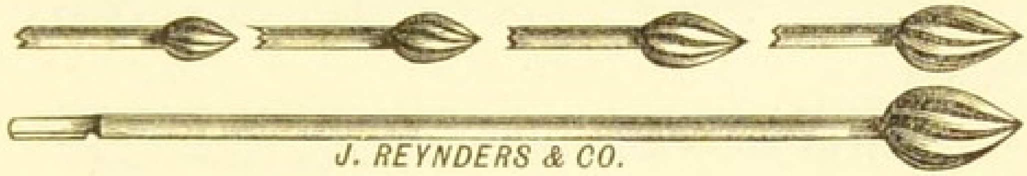

FIG. 30.

the near future. This statement is made upon a thorough knowledge of the principles involved in the

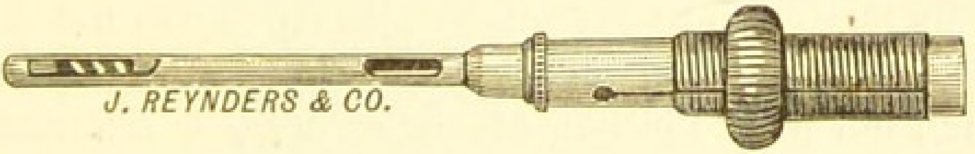

FIG. 31.

construction of all types and makes of electric motors, and a practical acquaintance with all the leading motors upon the market. This motor is shown separ-

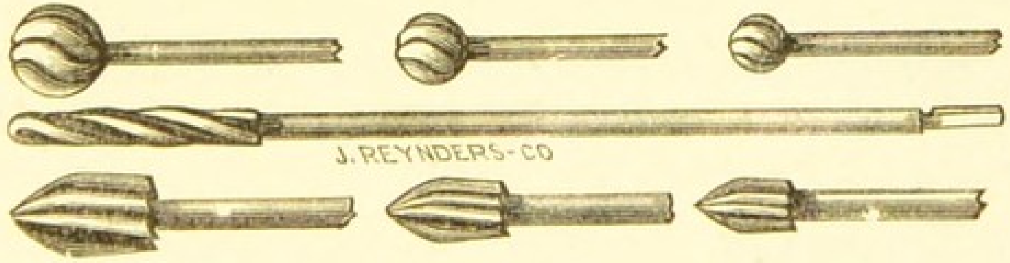

FIG. 32.

ately in Fig. 35, and is also shown in Fig. 28 in connection with the author's cabinet, where it is seen in position for driving the static machine. To use it for driving the nasal burrs and trephines shown in Figs. 30 to 34, we have only to attach a flexible shaft, similar to that used upon dental engines, to the front end

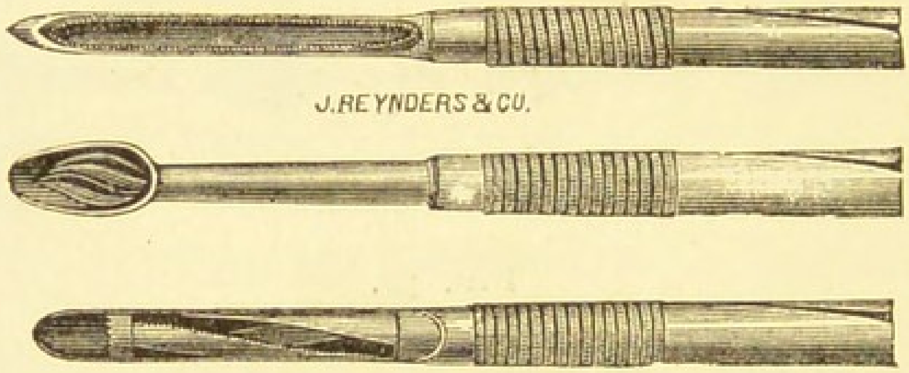

FIG. 33.

of the shaft (O, in the figure), where it will not interfere with its connection with the static machine. When not put to either of these uses, a fan may be

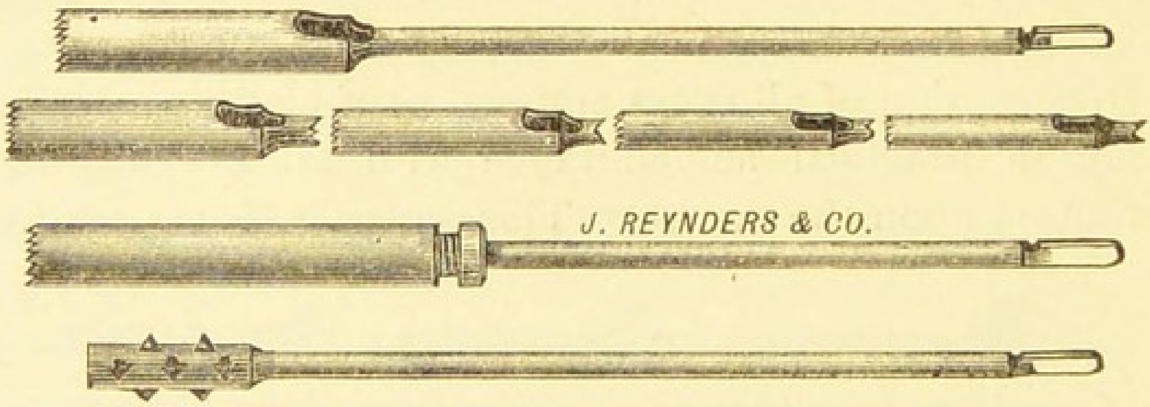

FIG. 34.

Figs. 30 to 34:—Olive-shaped, globular, cylindrical, and conical nasal burrs, trephines and saws that may be operated by the electric motor.

slipped on at O, and used to generate a refreshing breeze throughout the office. The motor should be 1-16 horse-power.

THE CURRENT TO DRIVE THE MOTOR may be had from either a primary or storage battery, or from the street electric light mains. If suitable electric light mains are in the neighborhood, this method is *decidedly* the best and cheapest. There are several kinds of mains, however, and before ordering a motor, the following information must be secured. Find out:

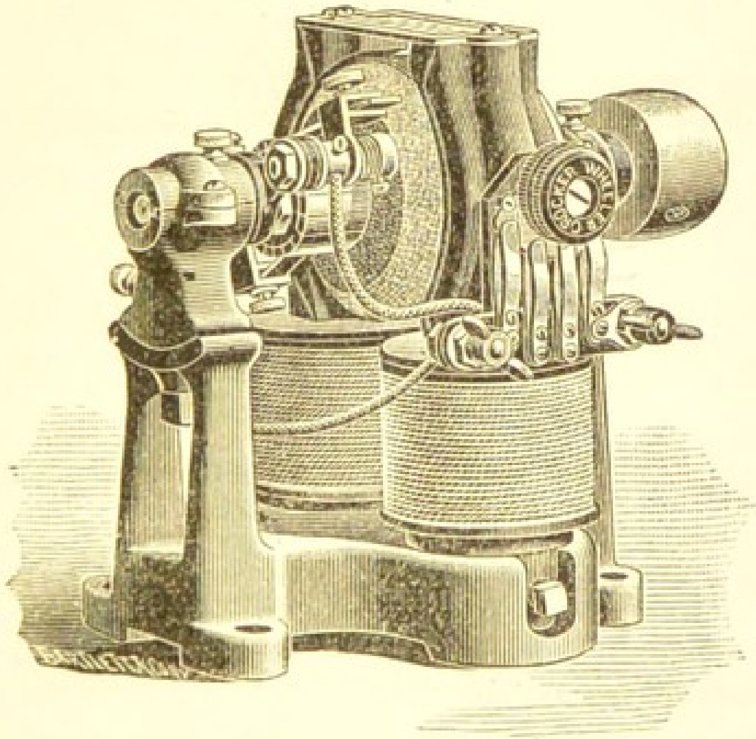

FIG. 35.—The Crocker-Wheeler Perfected Motor, 1/8 horse-power. Shunt-wound for constant potential circuits. Manufactured by C. W. & Co., New York City.

1st. If there are any electric mains in the immediate neighborhood of the office in which the motor is to be placed, and if the Company will run a wire into the office for an income of from one to three dollars per month:

2d. The character of the available mains—whether they are "*constant potential*," or "*constant current*:"

3d. What the *potential* is in *volts*, if the available mains are of constant potential; and what the *current* is, in amperes, if they are constant current mains:

4th. If the available mains are energised both day and night:

5th. If the available mains are energised with a "*direct*," "*continuous*," current, or with an "*alternating*" current.

This information will be necessary in order to determine upon the form of motor to order. A motor that would be suitable for one of these several kinds of currents, would be entirely inoperative in connection with any one of the others.

Constant potential mains are *generally* used in connection with the distribution of the little glow lamps, known as "*incandescent*;" while constant current mains are *generally* used in connection with the large intense lights known as "*arc*" lamps.

The motor must run at constant, uniform speed, independent of the varying loads which may be placed upon it. In order to effect this, one form of winding and regulation is adopted for the constant potential mains, and another one for the constant current mains. What is known as a "*shunt*" wound motor must be used for the constant potential mains;

and what is known as a "series" wound motor in connection with an automatic brush regulation, must be used for the constant current mains. The constant potential is greatly to be preferred, for very many reasons. These mains generally have a potential of either 50, 110 or 220 volts. If it is found, then, that the available main is energized during the desired office hours, and that it has a constant potential of 110 volts. Order a 110 volt "*shunt wound*" motor of $\frac{1}{8}$ horse-power. The motor shown in Fig. 35 is such a motor. It is self-regulating. To connect it to the main, run two No. 16 "office wires" from the two poles of the motor and connect them, one to each of the main wires, as they enter the house. A lightning arrester similar to that shown in Fig. 36, should be connected with each wire just before it enters the house. Somewhere in the circuit, conveniently located, there should also be inserted what is known as a "*fusible plug*," designed to carry not more than 1½ amperes. These latter are simply strips of lead that will fuse and break the circuit when a current of greater volume than the motor is designed to carry enters the office. These precautionary measures are necessary for the preservation of the motor and the protection of the office from fire. With these, an accident will be impossible.

The constant current mains generally carry from 9 to 11 amperes and have a voltage ranging from 500 to 3000 volts. These mains are dangerous to life, and must be handled *very* carefully. All parts of the circuit within the office must be thoroughly insulated, and the bare wires should *never* be touched.

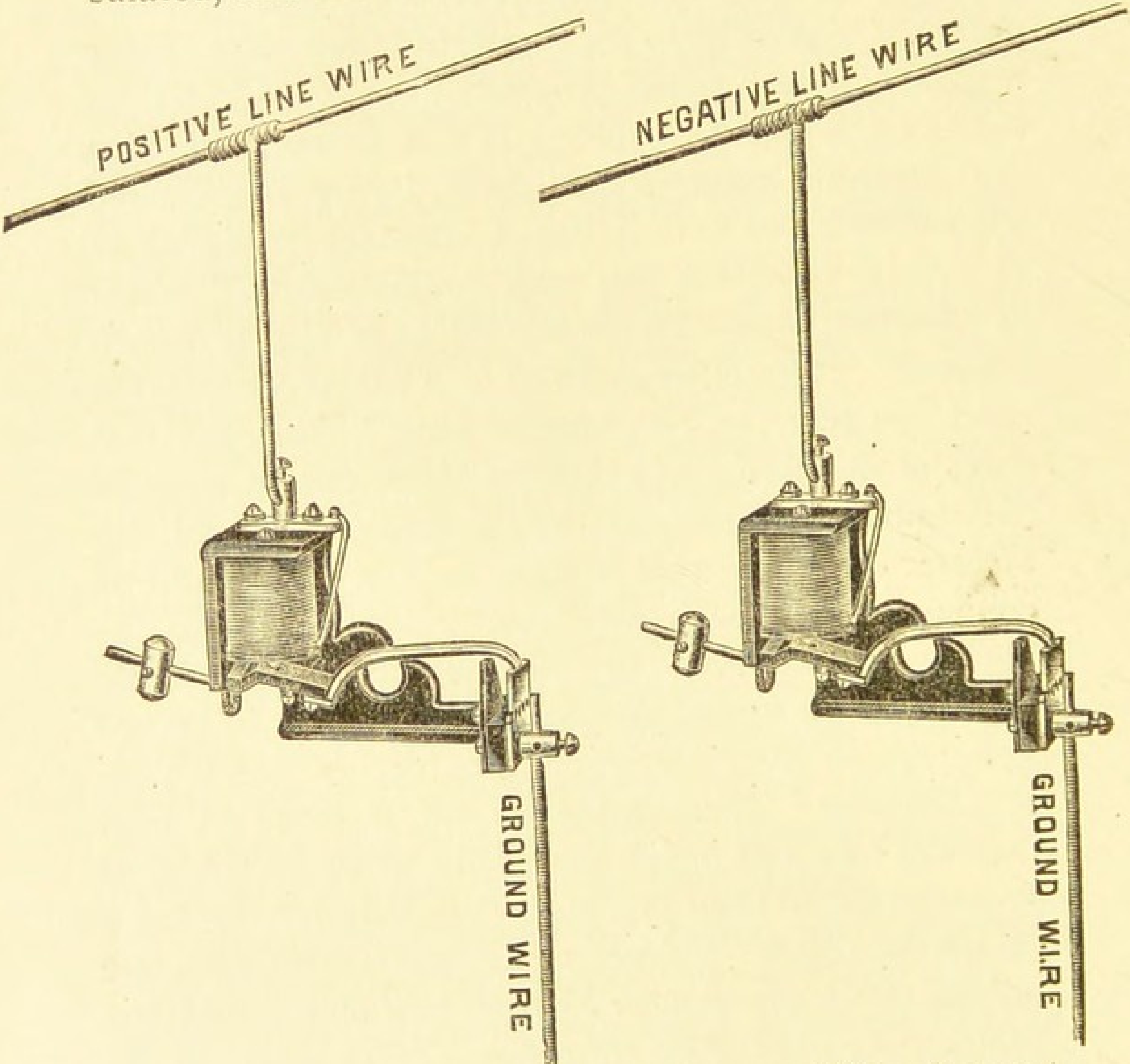

Fig. 36.—The Sperry Lightning Arrester. Manufactured by the Sperry Electrical Co., Chicago.

A lightning arrester will be necessary here also. The fusible plug, however, must be dispensed with, and its place occupied by an "*automatic cut-out switch*," to establish a short circuit around the motor in case of a break somewhere in the motor circuit, thus saving the continuity of the circuit. Without this latter device, the physician might occasionally be the means of putting out all of the lamps on the circuit, which would be likely to cause the company to remove his wire; besides, a fire might be caused by such an accident. If the mains carry a ten ampere current, then order a ten ampere "*series-wound*" motor with automatic brush regulator for maintaining constant speed.

The "*alternating*" current will seldom prove useful to the physician, because he can neither charge a storage battery nor run an ordinary motor with it. Cautery knives may, however, be operated directly.

In case of a temporary "*shut-down*" at the central station, either the 50 or the 110 volt constant potential motor may be operated by the 90 Leclanché cells in the author's cabinet, and these may be advantageously and most economically used at all times in those cases where the motor is to be used only occasionally for very short periods. But wherever the motor is to be used much and for long periods at a stretch, the direct supply from the constant potential mains is to be preferred.

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*Alternating current motors have very recently been placed upon the market, but their usefulness is quite limited. They must run at a fixed speed, and they cannot start from rest with a full load.

The next best source of supply, where available mains cannot be found, or where there is no working circuit during office hours, will be found to be the "*storage*" or "*secondary*" battery. These may be

Fig. 37.—The McIntosh Storage Battery.

charged from either direct constant potential or constant current mains, preferably the former. Hence, if a current may be had from mains for only a few hours out of the twenty-four, then it will be best to purchase a good storage battery with two cells, giving an electro-motive force of 4 volts, and capable of giving a current of at least 25 amperes, with a capacity of at least 300 ampere-hours (that is, capable of producing 25 amperes continuously for 12 hours, or one ampere for 300 hours). This battery may then be switched on to the mains and "*charged*" during the period that they are energized, and then the battery used to run the motor during the intervals. Such a battery will also operate *any* cautery electrode, but it will not operate more than a 2-candle-power incandescent lamp.

If there are no available mains in the neighborhood of the office, the storage battery may be taken to the central station occasionally to be charged; but if no very convenient means is at hand for carrying a 75-pound battery to the station, then it will be best to charge it by means of a number of cells of the "*gravity*" battery shown in Fig. 38. There should be from two to three of these for each storage cell; they should be arranged in the manner shown in Fig. 39. When the storage battery is not in use, the switch in front of the binding-posts is turned to the right, and the gravity cells thus placed in circuit with the storage cells, the positive to the positive, and the negative to the negative. When the storage battery is to be used, the switch is turned to the left, which throws out of circuit the gravity cells and connects the storage cells with the binding-posts. Both the storage and gravity cells may be placed in a neat, compact cabinet as shown in Figs. 40 and 50. The "*gravity*," or sulphate-of-copper battery, is what is known as a "*closed circuit*" battery, and it is the only primary battery suited to the charging of secondary cells. The open-circuit cells, such as the Leclanché type, are not suited to the purpose. A rheostat should accompany this outfit.

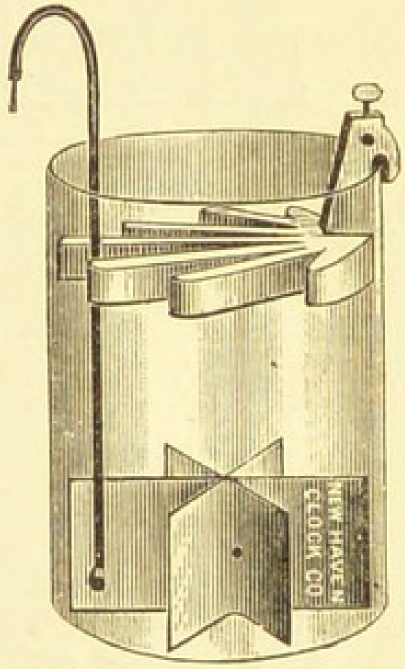
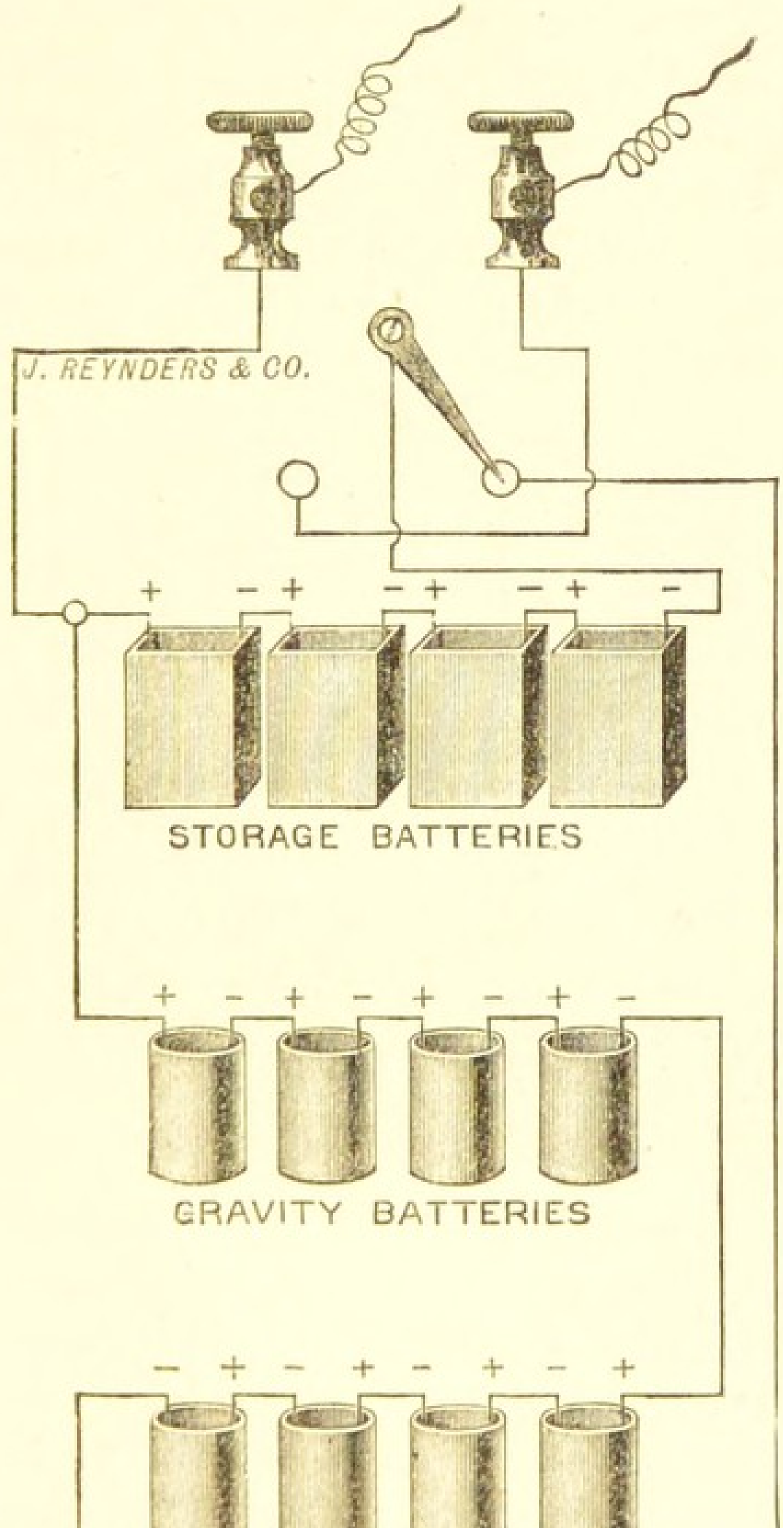


Fig. 38.—Gravity Battery of the New Haven Clock Co.

If a primary battery is to be used to run the motor, the "No. 11 cell" of Mason's primary battery, made by James H. Mason, of 118 Park Avenue, Brooklyn, N. Y., will prove the best, giving the least trouble, and proving the most economical for a primary battery. Three of these cells, such as shown in Fig. 41, will be required. Unlike most primary batteries, this one does not "*polarize*" readily, and it is


J. REYNDERS & CO.
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STORAGE BATTERIES
+ − + − + − + −
GRAVITY BATTERIES
− + − + − + − +
GRAVITY BATTERIES

Fig. 39.

not subject to the formation of crystals within the cell, nor is it necessary to remove the zinc when the cell is not in use. Each cell has a low internal resistance, and has an electro-motive force of 2.1 volts, and will give a current of 15 amperes for 23½ hours; in other words, it has a capacity of 350 ampere-hours.

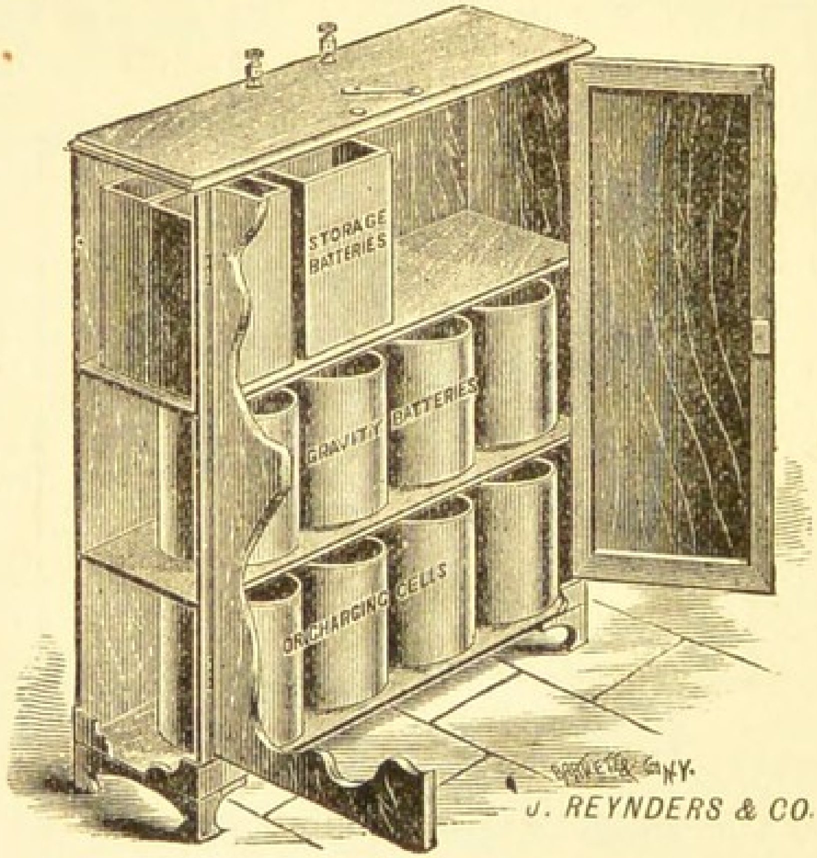


Fig. 40.—Storage and Gravity Battery Cabinet.*

It costs about 75 cents to run the motor with this battery for 12 consecutive hours of active service at full capacity (⅛ H. P.).

In ordering motors to be run by two cells of storage battery, call for a 25 ampere motor requiring an electro-motive force of 4 volts.

* Waite and Bartlett also make such a cabinet. See Fig. 50.

In ordering motors to be run by three cells of Mason's primary battery, call for a 15-ampere motor requiring an electro-motive force of 6 volts.

Storage or Secondary Batteries of varied forms are upon the market, some utterly worthless, others very serviceable and economical. All storage cells have an electro-motive force of two volts. The commercial cells, as a rule, are intended to be dis-

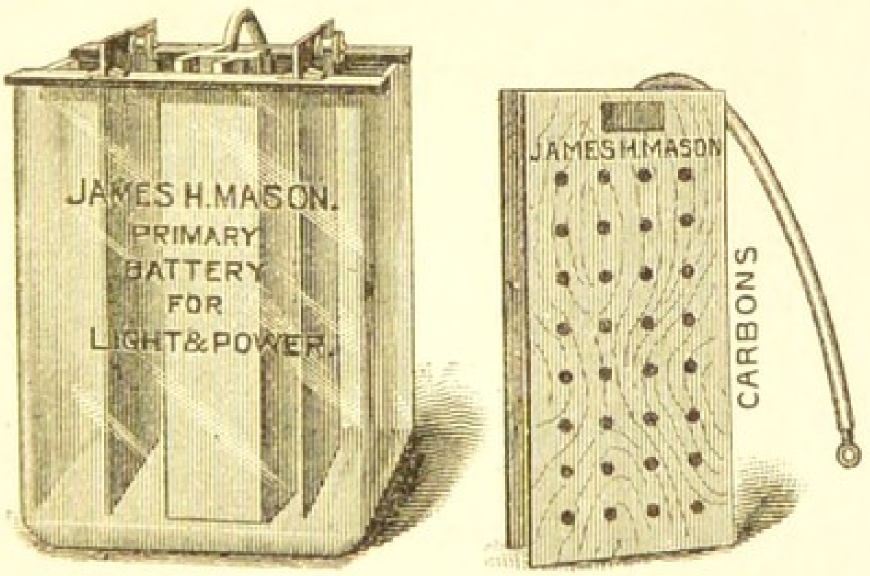


Fig. 41.—Mason's Primary Battery.

charged at the rate of from 20 to 30 amperes per hour; and they have a capacity of 350 ampere-hours per cell. Each pair of elements in a cell must have about 6 square inches for each ampere-hour of current. From these data it should be an easy matter to calculate the size and number of pairs of plates required for a battery of any required power. Of all the storage batteries upon the market at the present time, the one manufactured by the McIntosh Co., of Chicago, will prove best suited to the requirements of the medical man. This is shown in Fig. 40. Three sizes of these are manufactured—a "small," "medium," and "large." It will prove poor economy, however, to purchase any but the large size. These have two cells, producing an electro-motive force of 4 volts, and having a capacity of about 100 ampere-hours. They are provided with a rheostat which enables the operator to regulate the current to a nicety. They will operate any cautery electrode from the smallest to the largest, or they will run a low resistance motor. In dealing with a storage battery, the greatest care must be exercised to avoid short-circuiting it—that is, bringing the poles or the cords attached thereto in immediate contact. If this should happen, the battery may be almost immediately discharged, and perhaps ruined. Its potential should be occasionally tested with the volt-meter, and as soon as the normal electro-motive force begins to show a falling off, the battery should be recharged. It should never be discharged at the rate of over six amperes per square foot of active or anode surface.

Not over thirty per cent. of the full capacity should be withdrawn before recharging.

The electro-motive force should never be allowed to fall below 1.9 volts. After the electrolyte is once put into the cell it must not be allowed to stand without a charge. It must never be charged at the rate of over three amperes per square foot of anode surface.

A disregard of these injunctions will result in injury, and may cause a complete destruction of the battery. Full directions for charging accompany each battery, hence there is no necessity for a discussion of that point here.

CAUTERY ELECTRODES have been designed in great variety, as regards form and special adaptation to the various parts of the body. They are all made of copper wire tipped with platinum.* Those with a large surface or cross-sectional area of platinum require a large volume of current, while those with less surface or cross-sectional area of platinum require less current. The large loops of wire forming the snares, require comparatively less volume, but a higher electro-motive force.

Electrodes designed for the nose and throat should be quite light and slender; those made by J. Reynders & Co. being the best. See Fig. 42. The handles for these should also be very light and compact, as shown in Fig. 43.

A variety of excellent cautery electrodes for general surgical work is shown in Fig. 44. These are made by Mc Intosh, who also makes a very good cautery snare and universal handle, shown in Fig. 45. Other forms of handles, either of which are good, are shown in Figs. 46 and 47. Extra heavy

*A current of from 5 to 40 amperes, according to the size of the tip, passed through these electrodes will render the platinum tip incandescent.

electrophores or connecting cords will be required for all the large cautery electrodes. The tips should always be brought up to a white heat before being brought in contact with the tissues to be destroyed or

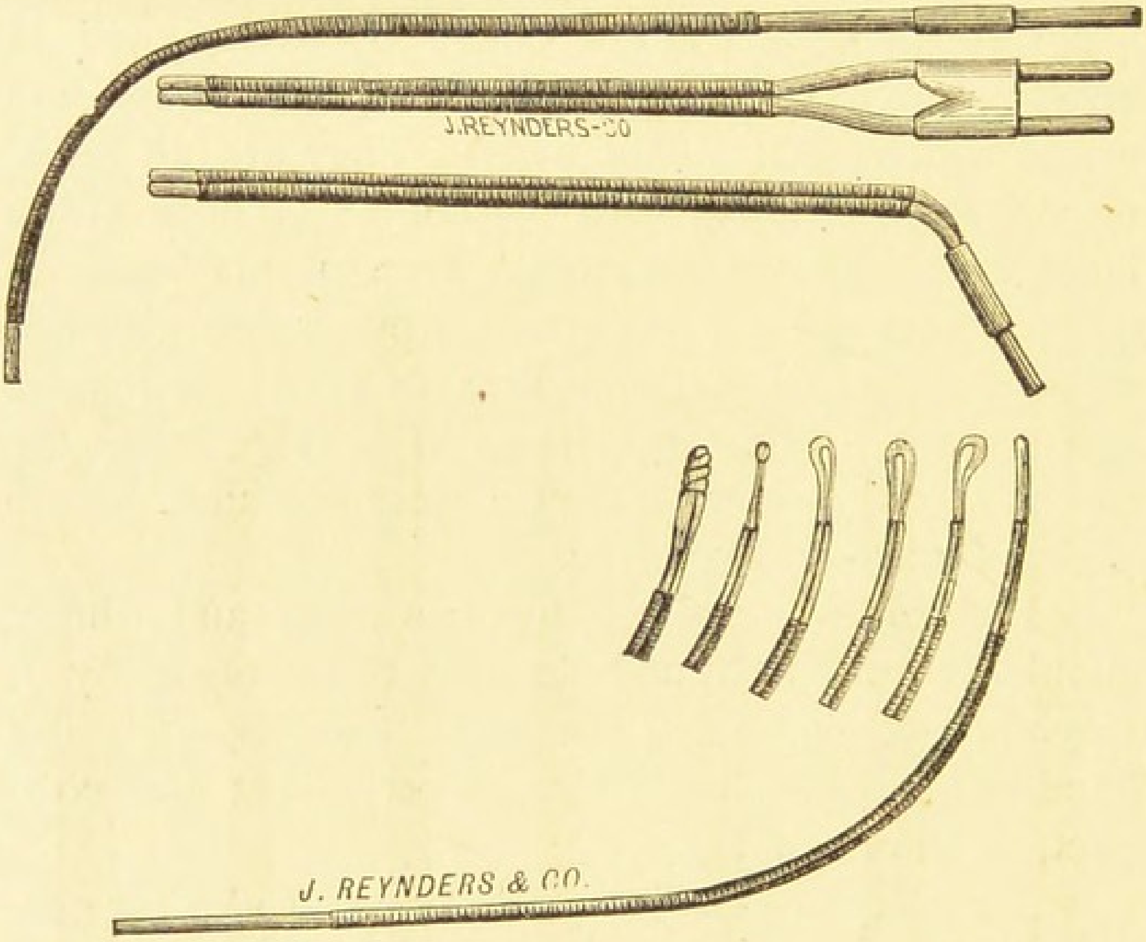


Fig. 42.—Cautery Electrodes for operations upon the nose and throat.

excised. After the tip is imbedded in the tissues, the current should be slightly increased, but great care must be exercised lest the tip be fused.

A Primary Cautery Battery is very necesary for all work outside of the office, because they are lighter and more portable than the storage batteries. The

the "C and C" Battery, illustrated in Figs. 48 and 49. It has two cells, with a combined electro-motive force best and cheapest battery suited to this purpose, is

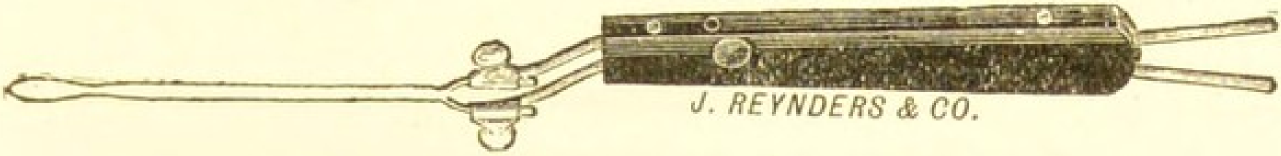


Fig. 43.—Small Handle for Nose and Throat Electrodes.

of 3.9 volts, a resistance of .06 to .15 of an ohm, and produces a current of from 30 to 45 amperes. The

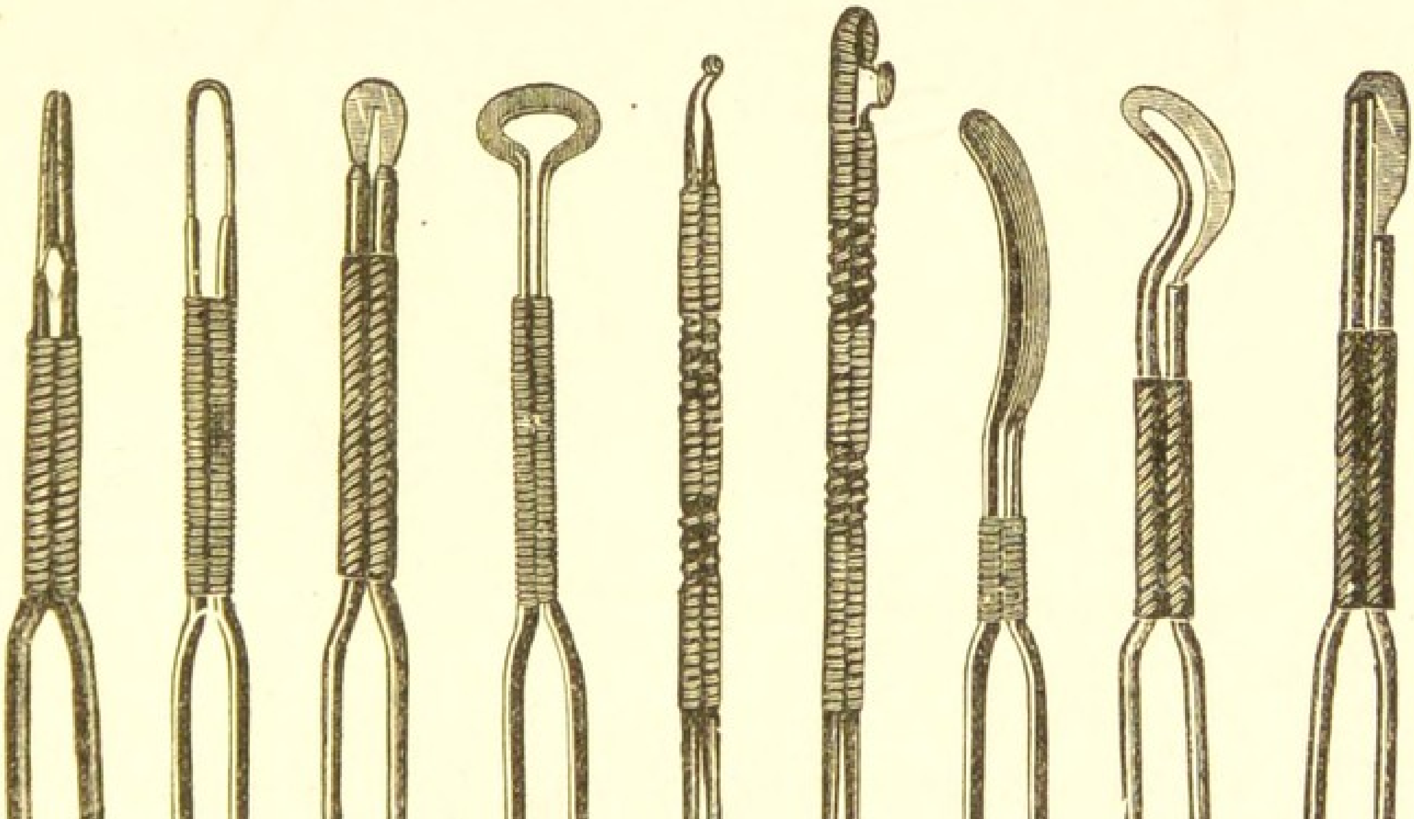


Fig. 44.—Cautery Electrodes for General Surgical Work.

complete battery weighs but 20 pounds, its size being 8x12x12 inches. The two cells are in series, and the elements are balanced by a spring, so that by means of a lever on the outside of the box, these may be immersed in the solution to any required depth. By lowering the elements into or raising them out of the solution, the strength of the current is increased or

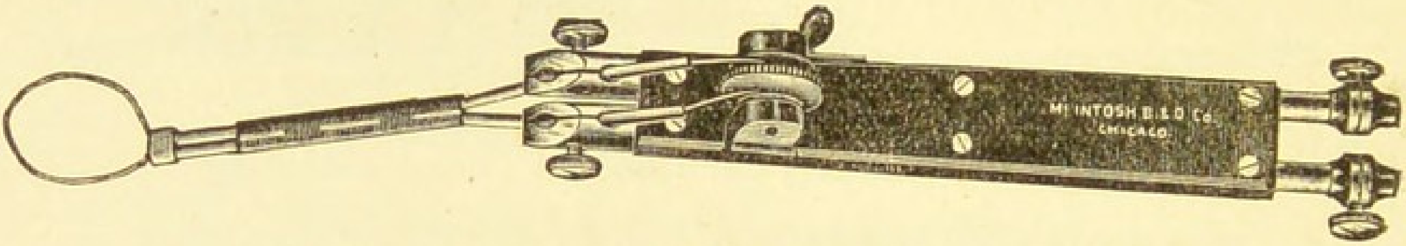


Fig. 45.—The Mc Intosh Cautery Snare and Universal Handle.

diminished at will. This battery may also be used for running a small low resistance motor, but it is not the best for this purpose, since it polarizes rapidly

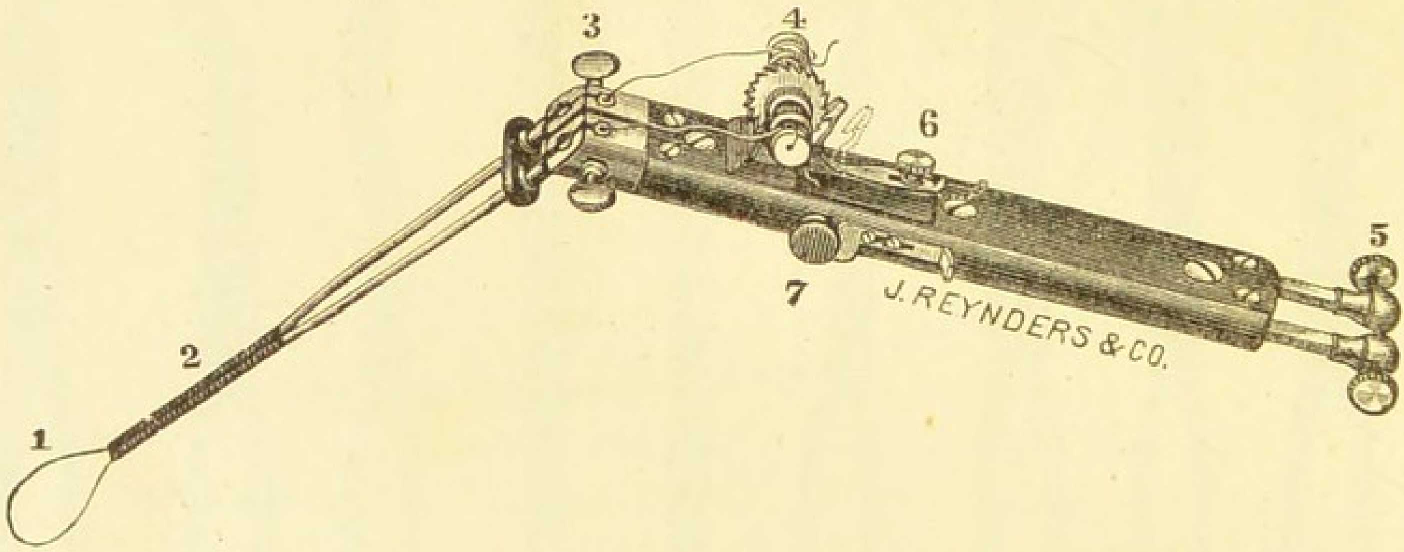


Fig. 46.—Reynder's Cautery Snare and Universal Handle.

under a rapid and heavy discharge for any considerable continuous period, will require very frequent renewals of the fluid, and annoying crystals will form in the cells. But for light eye, ear, nose and throat cautery work, or for all kinds of cautery work outside of the office, providing a sufficient number of cells be employed, it cannot be surpassed. The platinum electrodes may be given any desired degree of incandescence by a simple manipulation of the lever. A dry compound packed in

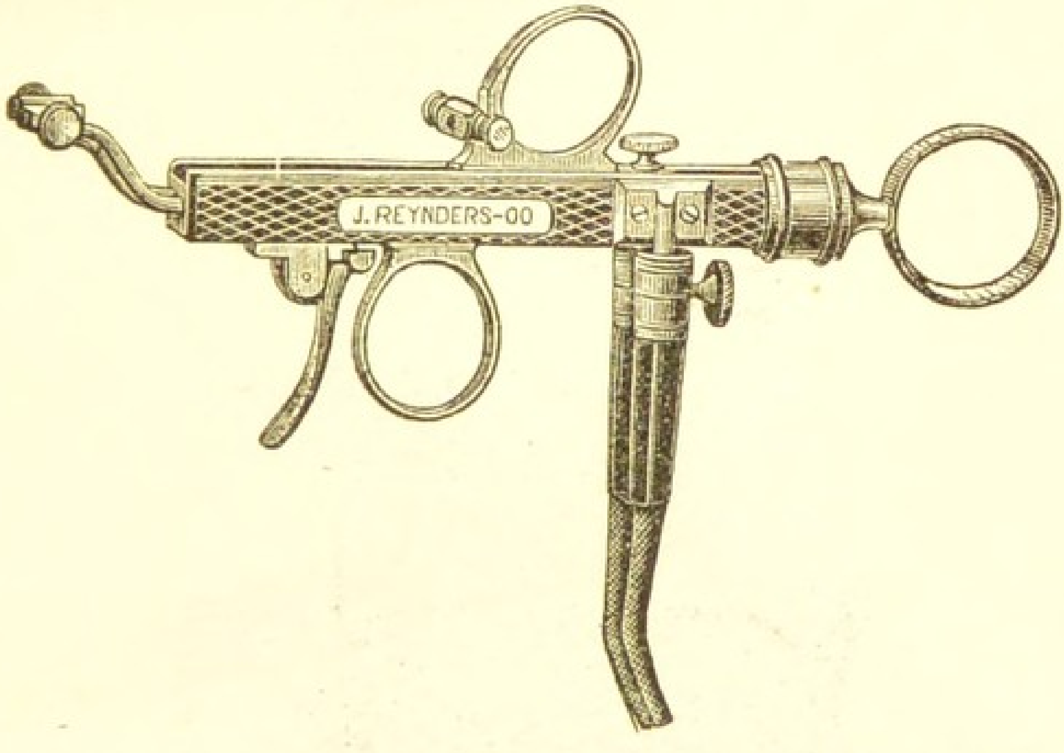


Fig. 47.—A Second form of Reynder's Cautery Snare Handle.

tins supplied for this battery makes it perfectly safe and easy to handle. A freshly charged battery of two cells has a capacity of 50 ampere-hours. The smallest motors ($\frac{1}{20}$ horse-power) require 10 amperes per hour, so that this battery will run one of these motors for 5 hours, but not continuously, because of the polarization before referred to.

For the heavy cautery work, such as operating the large cautery knives and long snares, four cells will be required. These batteries are made four cells

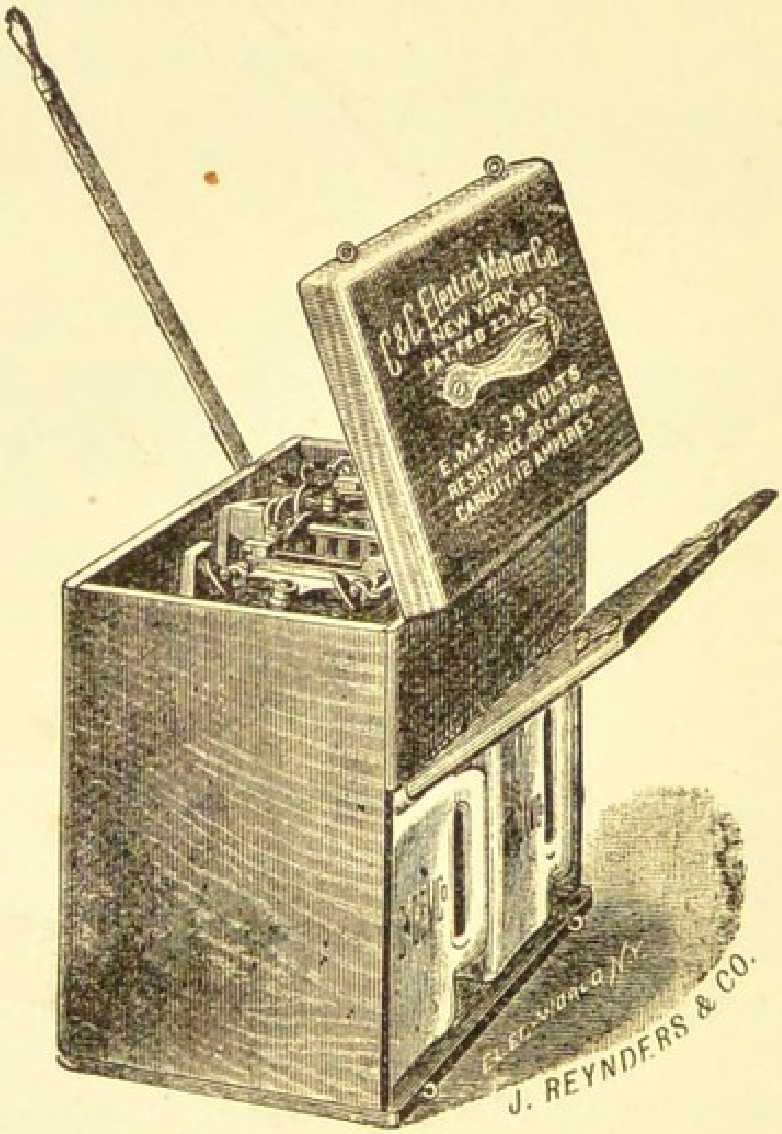


Fig. 48.

to one case, but it will be found to be best to purchase two batteries of two cells each, then the two can be taken out only when heavy work is to be performed. The two small batteries will be easier to carry than the one large one. To operate the large cautery knives, the two batteries should be coupled up in parallel for great volume, while to operate the

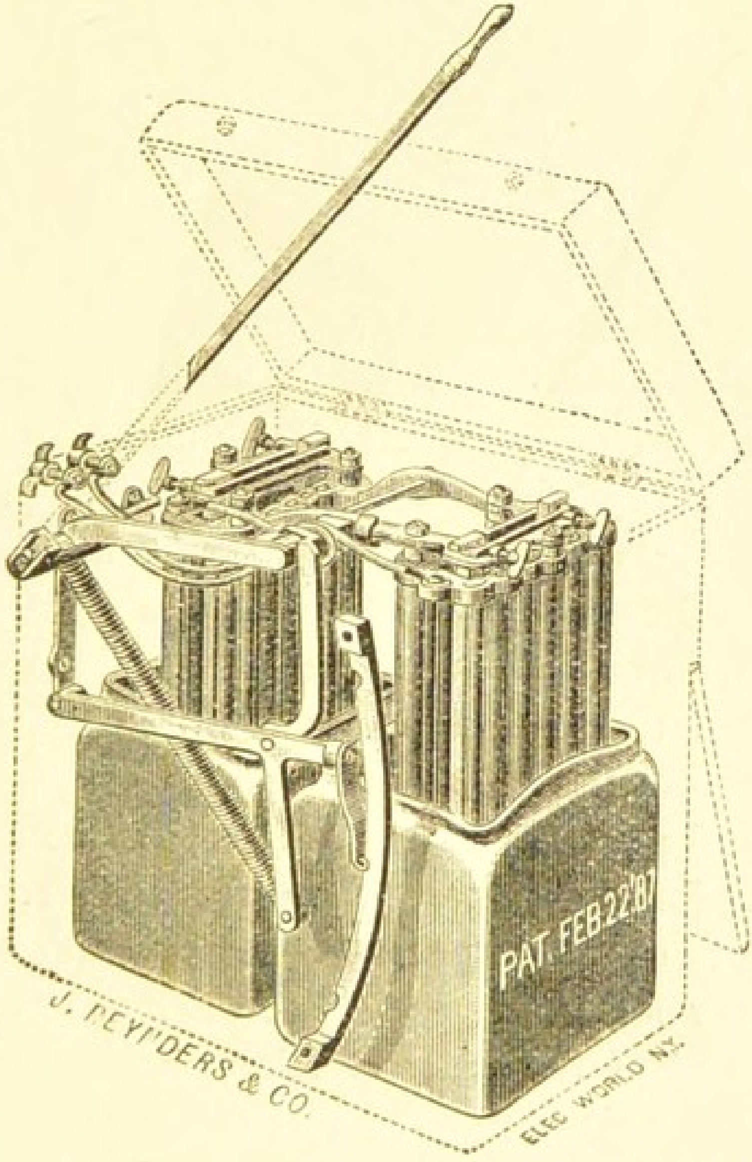


Fig. 49.

long snares, they should be coupled up in series for high electro-motive force. From the four cells, either double the volume or double the electro-motive force of the two cells may be had, according to the manner of coupling them up. The battery of two cells will barely operate a ½ candle-power lamp, but four cells will operate as high as a 6 candle-power lamp, which requires from 6 to 7 volts. These batteries may be obtained for only $13 per pair of cells contained in a nice hard-wood box, as shown in the illustration—Fig. 48.

In operating motors for driving drills, etc., and static machines, and in operating exploring lamps and cautery electrodes, where both hands of an operator may be employed, it is very desirable to have a floor-switch arranged in the manner shown in Fig. 50, whereby the work may be started and stopped by means of the operator's foot. It is still more desirable to have this switch a rheostatic one, which will enable the operator to not only stop and start the work, but will also enable him to regulate the speed of the motor or the degree of incandescence of the exploring lamps and cautery electrodes, by a movement of the foot. A device which may be utilized for such purposes is shown in Fig. 51. It may be had of the Detroit Electric Motor Co., Detroit, Mich. An ordinary resistance box, the wires of which must be capable of carrying 40 amperes, is to be placed upon the back of the upright portion, and connected up with the series of plates forming the switch. The upright portion may be disconnected from the foot attachment at any time and operated by hand. This will prove suitable for

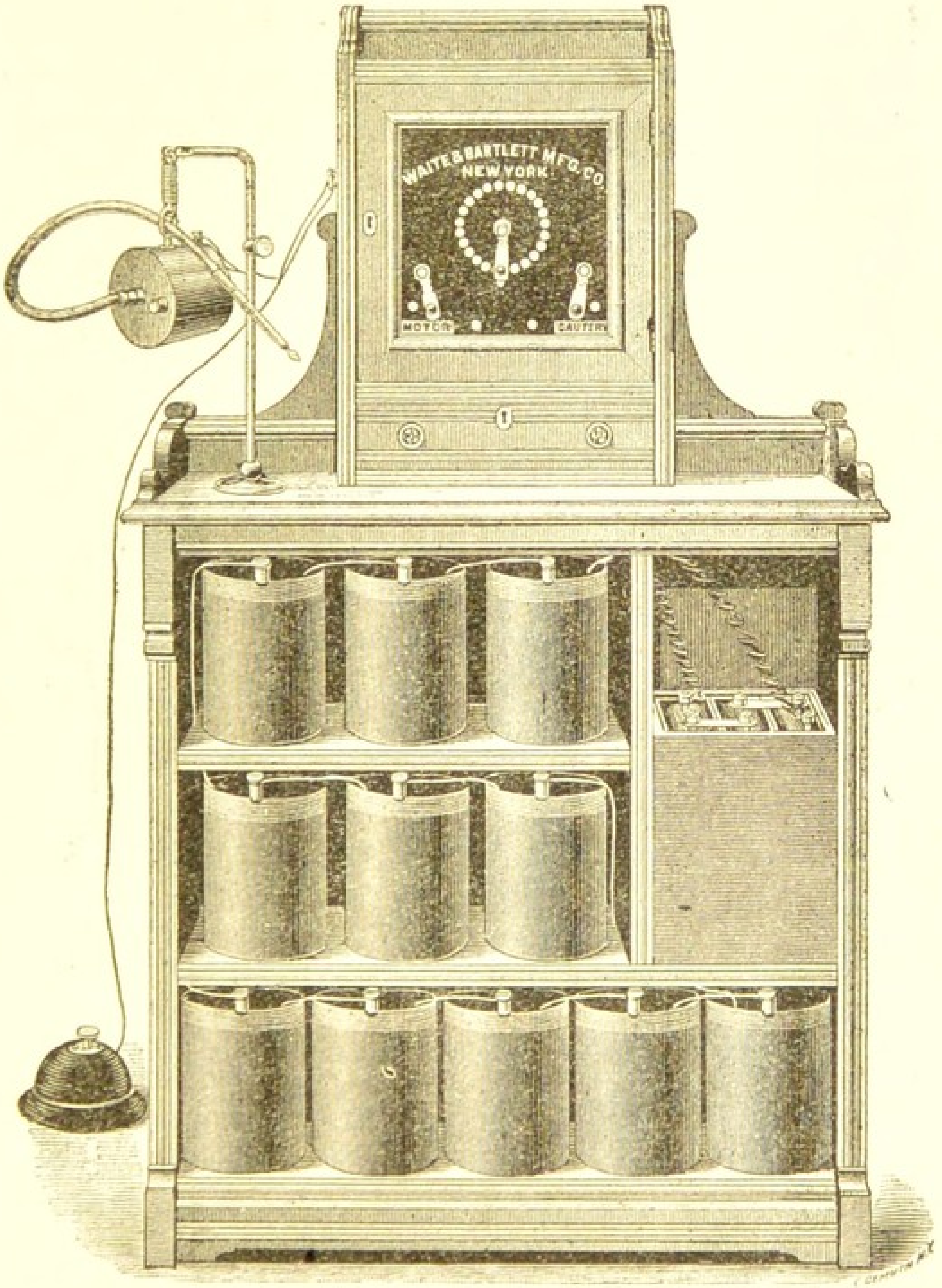


Fig. 50.—Method of Introducing Floor-Switch for Foot-Control of Motors, etc.

controlling the current from street mains. from storage batteries, or from any primary "*open-circuit*" battery, such as the Mason for example. It is connected with the circuit in the manner shown in Fig. 50. Pressure with the foot lowers the switch-lever and thus removes resistance from the circuit; the spring bringing the switch-lever back to its original position, when the pressure is removed.

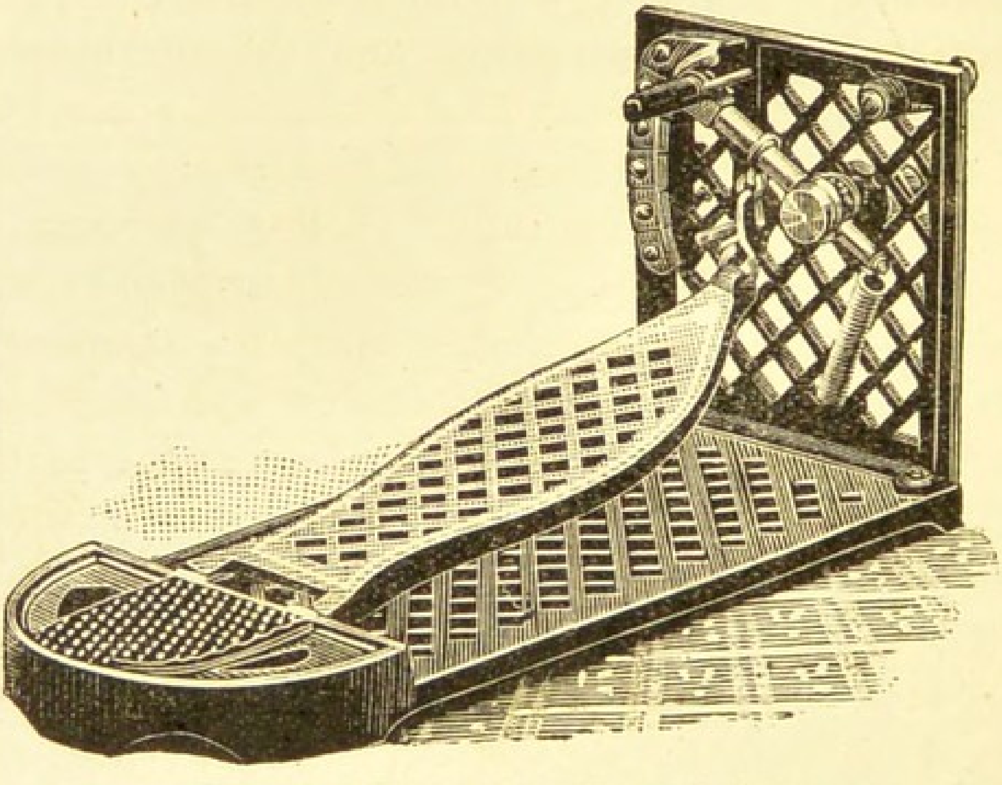


Fig. 51—Rheostatic Foot Switch.

Electric Exploring Instruments and Lamps. —The application of electric illumination to medical and surgical explorations, was first made by the author in 1879, the "*Electric Laryngoscope*" and the "*Electric Operating Otoscope*," being the first electric exploring instruments brought before the profession.

These instruments were invented by the author in 1879, and first described by him in the New York *Medical Gazette*, of May 22nd, 1880.* Since the introduction of these instruments, the principles of which were not patented, but freely given to the profession by the author, numerous other instruments, founded upon the same principles, for the examination of the bladder, the stomach, and the urethra, have made their appearance, with the respective titles of the cystoscope, the gastroscope, and the urethroscope. In all of these the principle is the same; a current of electricity is used to render incandescent a piece of platinum wire, or a filiment of carbon, enclosed in a glass bulb from which all of the air has been expelled. This lamp is mounted directly upon the instruments, and by means of a series of reflectors and condensors, the light thus produced is directed upon the parts to be illuminated, the image of which is then reflected back directly or indirectly to the observer. The author's laryngoscope and otoscope have not been improved upon. These are shown in Figs. 52 and 53. The lamp used in these instruments has a resistance of from 3.6 to 4.5 ohms, requires an electro-motive force of 5.5 to 7. volts, and a current strength of 1.5 amperes; giving 3 candle-power. Twenty cells of any

*See also "Rocky Mountain Medical Review," September, 1880; "Archives of Laryngology," 1880; "Medical Electricity," by Roberts Bartholow, 1881; and "Diseases of the Nose, Throat, and Chest," by E. Fletcher Ingalls, 1881.

Leclanché battery will operate them, four cells of the "C and C" battery, four cells of the Mason battery, three cells of any storage battery (where lamps of the lowest resistance are used), or any incandescent light mains, providing a suitable rheostat is used in connection therewith.

A very desirable method of employing the electric light for examinations of the mouth, superficial tissues of the eye, the vagina, the nose, and the rectum, is shown in Figs. 54 and 55. This instrument allows the free use of both hands. The weight is ½ oz. When

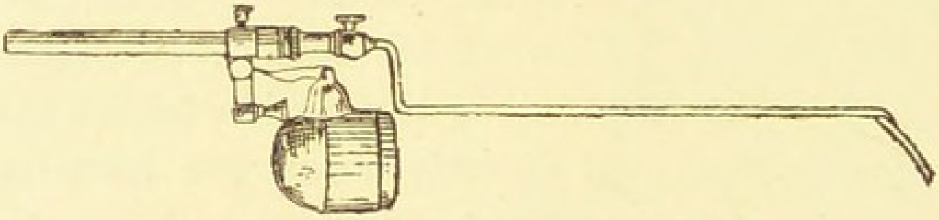


Fig. 52.—The Author's Electric Laryngoscope.

in use, it is worn the same as a pair of spectacles. Myopic and hyper-metropic operators can utilize the spectacle frame by inserting suitable glasses. Meyrowitz also makes a similar instrument with a head-band attachment in place of the spectacle frame. See Fig. 56.

The source of the electrical supply to operate this instrument, may be the same as detailed in connection with the description of the laryngoscope and otoscope.

Figure 54 illustrates the instrument complete. It is made of metal with a highly polished parabolic mirror. The outside surface is blackened in order to prevent the reflection of light to the eyes of the operator.

Fig. 57 shows an excellent instrument for illuminating the posterior nares, while making an examination through the anterior nares; it is also very use-

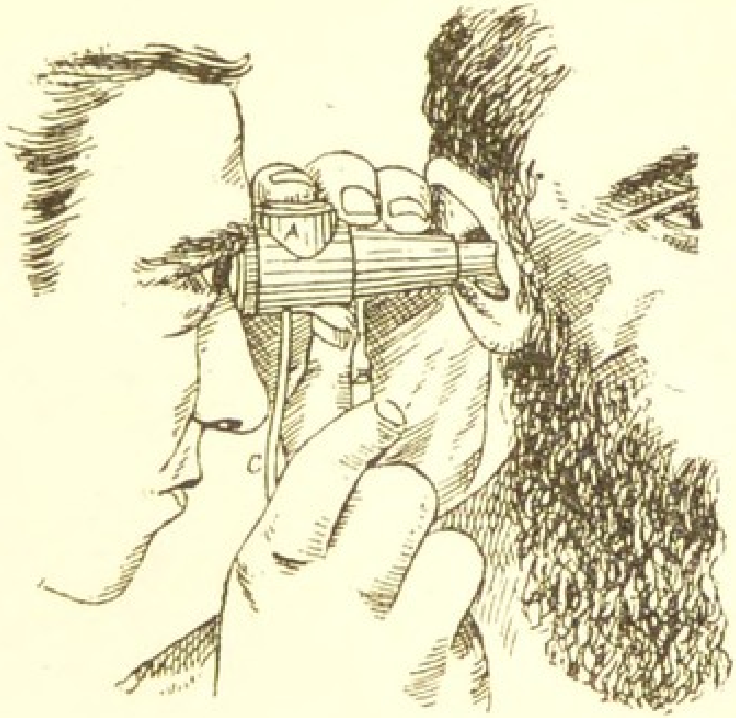


Fig. 53.—The Author's Electric Otoscope.

ful in illuminating all small cavities. It can be operated with two cells of storage, the Mason, or the " C. and C." battery.

Fig. 58 shows a very good method of mounting these lamps for use in connection with the microscope.

Fig. 59 illustrates the method of applying electric illumination to examinations of the urethra. To illustrate the cystoscope and gastroscope would be a needless repetition, since the principles are the same in all.

The different sizes of lamps used in these various illuminating and exploring instruments, in connection with all necessary data, are shown in Figs. 60 and 61.

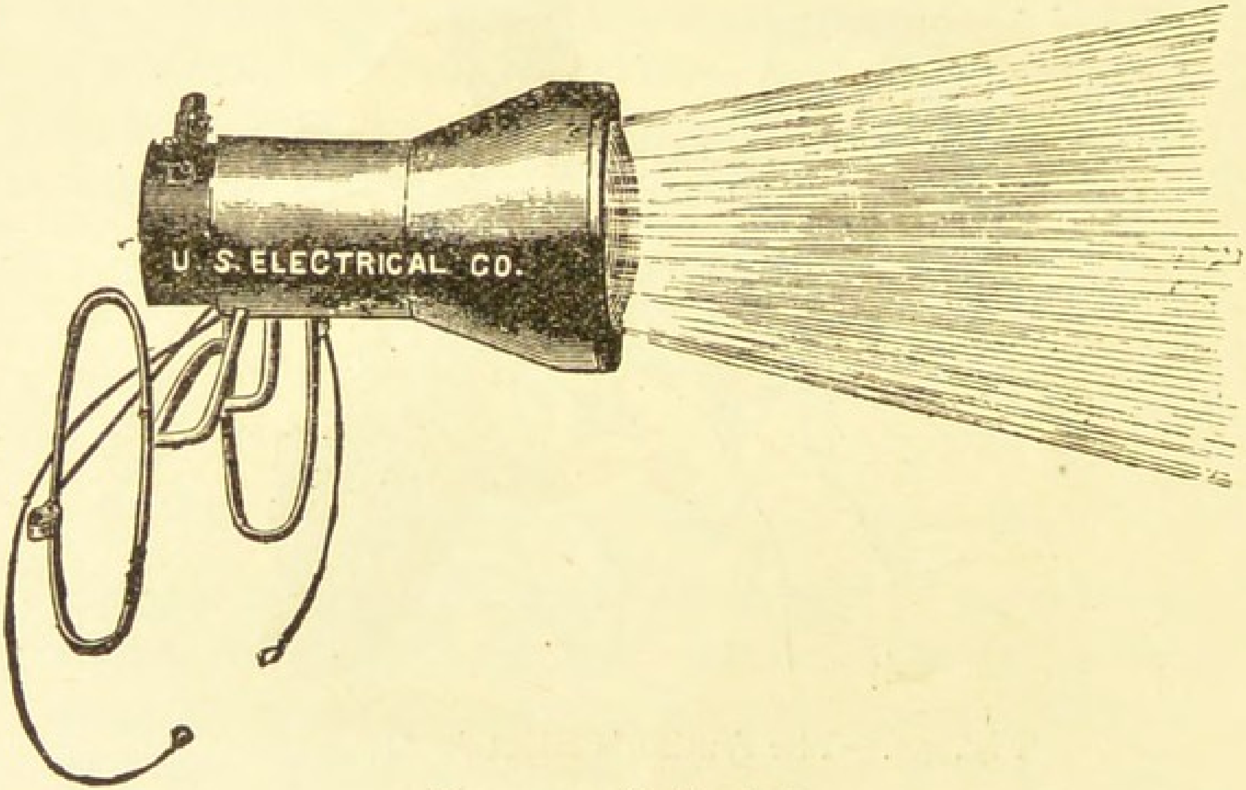


Fig. 54. (Full size).

These lamps are also very useful in connection with a Mason primary battery, for house illumination in cases of emergency—as, for instance, in night-calls, (see Frontispiece, Vol. I), when a button at the side of the bed may be pressed, and light immediately produced for dressing. On entering the hall, another button may be pressed and the hall thus illuminated. When the front door is reached, both lights may be extinguished by pressing a third button located near the front door. Thirty dollars will purchase such an outfit, and a dollar or two per year will maintain it. What physician, having it within his means, can afford to be without the advantages and conveniences of such an outfit?

Fig. 55.—Showing the manner in which this instrument is used. The flexible battery cords are carried directly from the instrument back over the head to the battery, which can be placed in any convenient position.

A Portable Galvanic Battery that will come up to our ideal, and meet all the requirements of the general practitioner, has yet to be invented. Acid batteries are a source of great annoyance, and yet they are the only ones thus far which will meet the requirements of the general practitioner in all classes of work. The Barrett chloride of silver open-circuit battery, which is simply a slight modification of the old Warren de la Rue battery, as manufactured by

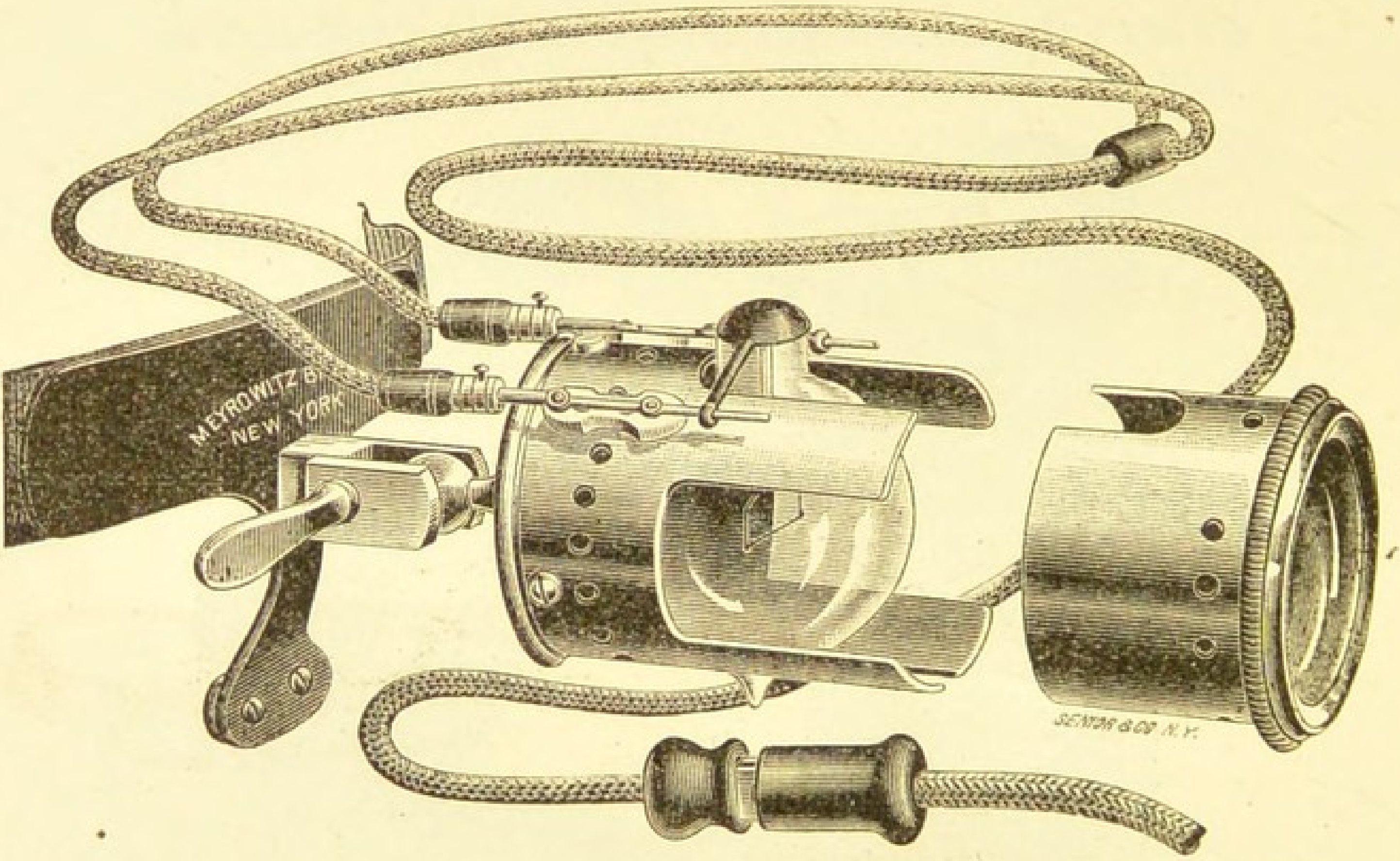


Fig. 56.

M. Gaiffe, of Paris, is undoubtedly the lightest, most compact, most cleanly, and most easily managed battery upon the market; but it has two *very serious* drawbacks, namely:

1st. It is not suited to electrolytic work and electro-chemical cauterization requiring very strong currents, such as are used, for instance, in gynæcological practice:

Since one cell will not give more than 45 milli-amperes through 11 ohms of resistance, one hundred cells in series can never give more than this— Additional cells only add to the electro-motive force so as to maintain the same current, or something less than it, through a higher external resistance, a condition of affairs due to the high internal resistance of these cells, which amounts to 7.7 ohms per cell, while the electro-motive force is only 1 to 1.07 volts; in practice, therefore, not more than 25 milli-amperes can be had from it:

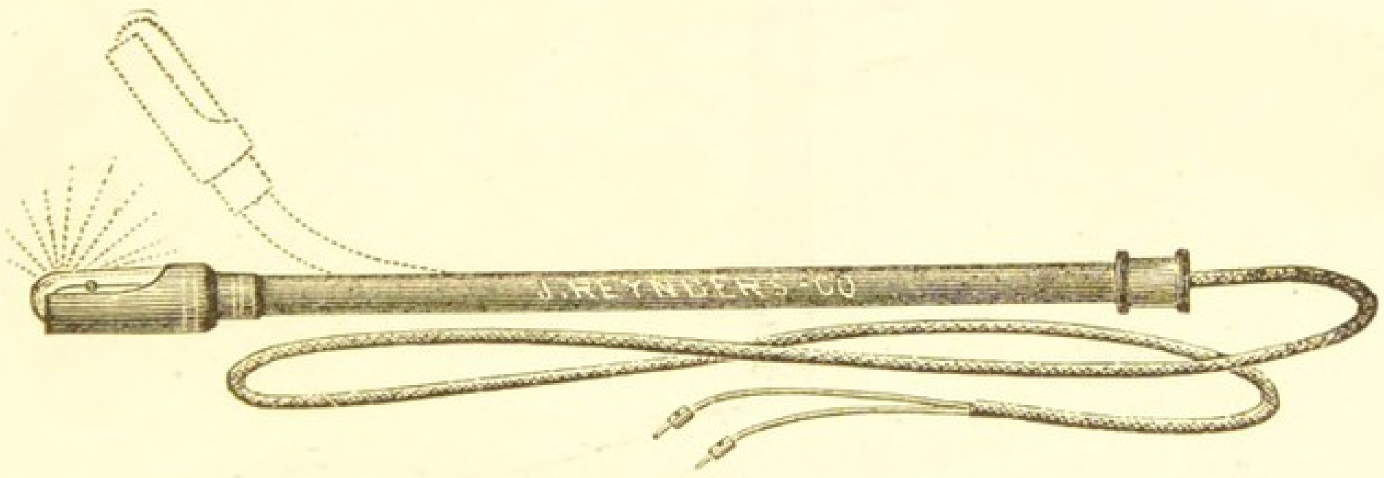


Fig. 57.—Instrument for illuminating the posterior nares and other cavities.

2d. It cannot be recharged by the physician, but must be sent back to the manufacturer when it becomes discharged, which an accident may bring about at any time.

All things considered, therefore, the best portable Galvanic battery upon the market up to the present time will be found to be the McIntosh. This is shown in Figs. 62 and 63.

The electrolyte is composed of sulphuric acid and bichromate of potash, and the elements are carbon and zinc, the whole being contained in a hard-rubber

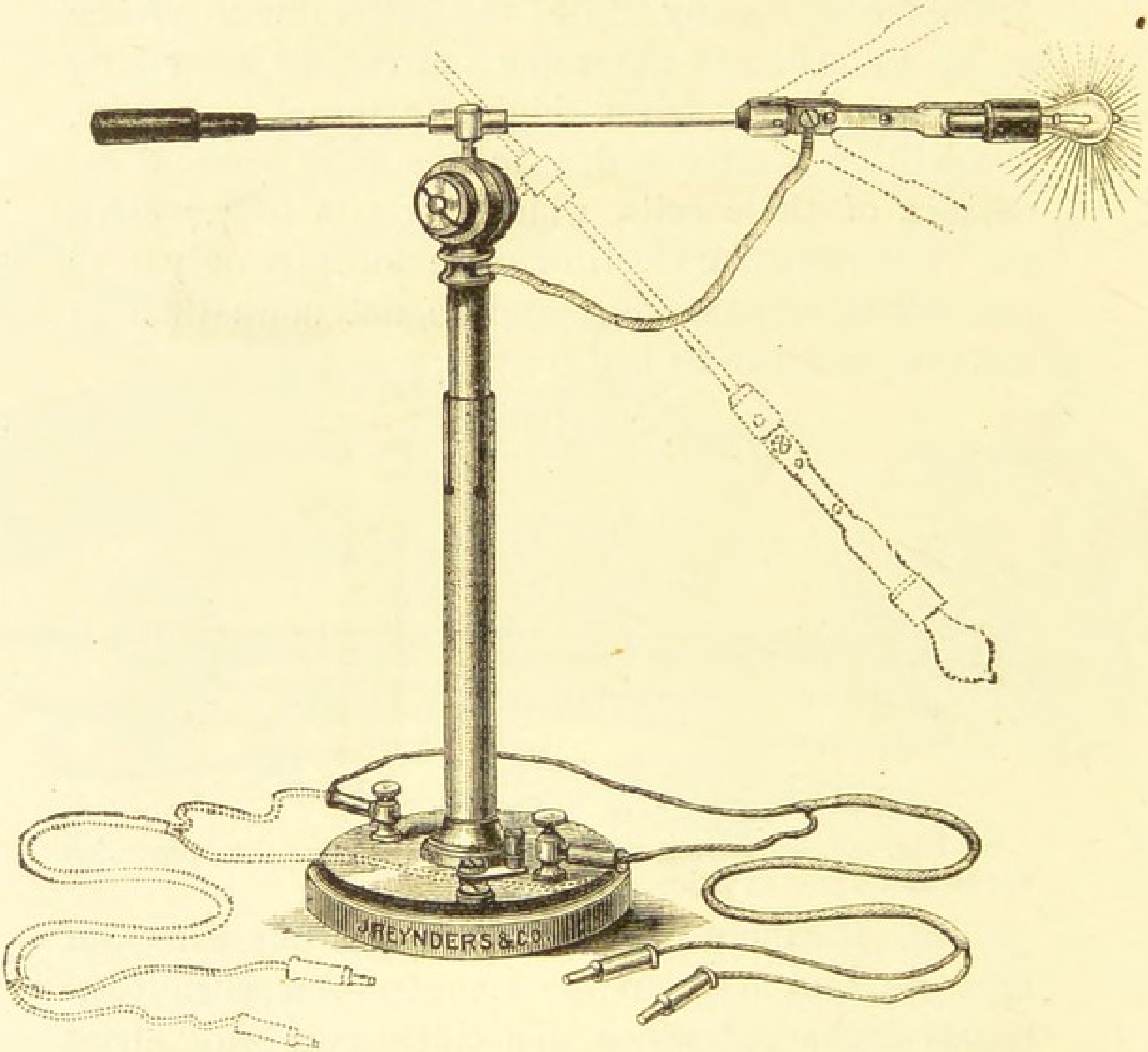


Fig. 58.—Illuminator for microscopic work.

cell. The electrolyte is placed in the small compartments shown in the foreground to the right of Fig. 62, and the elements, shown to the left of the same figure, are inserted in these compartments when the battery is to be used. When not in use, the elements are turned around and placed in the drip-cup shown in the background to the right of the same figure. These six cells constitute one division of the battery.

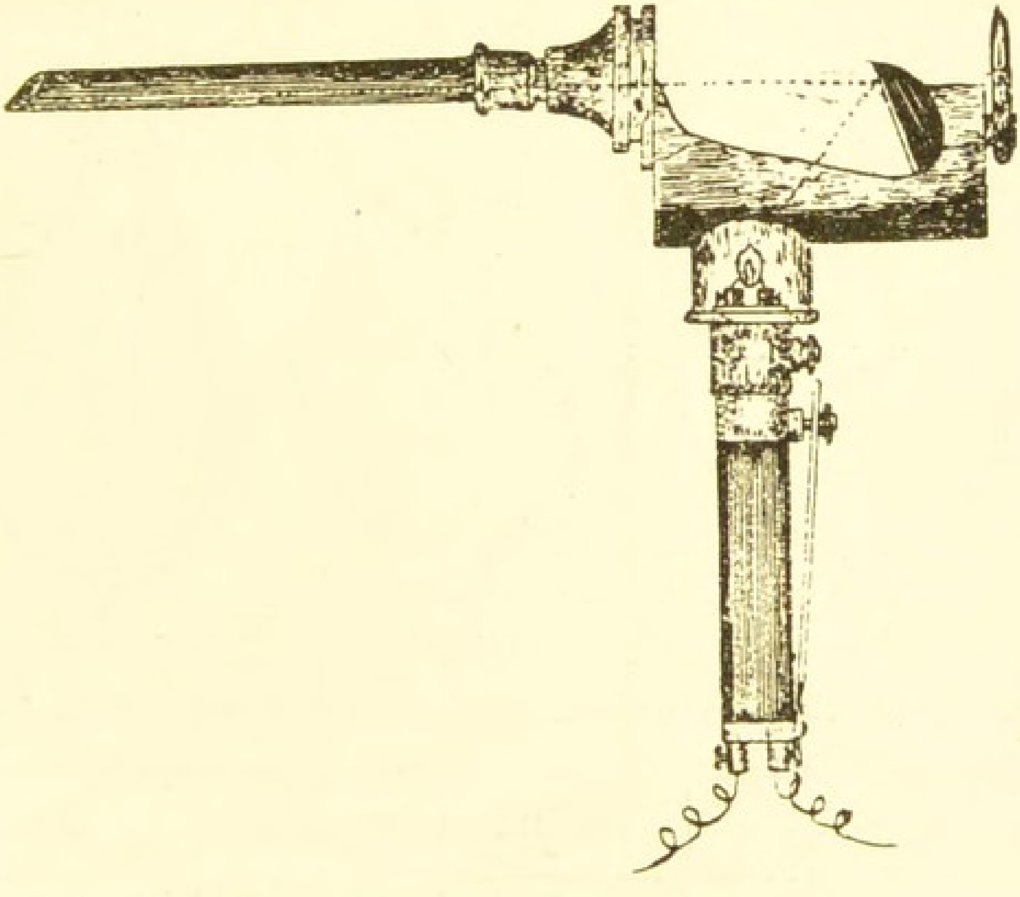
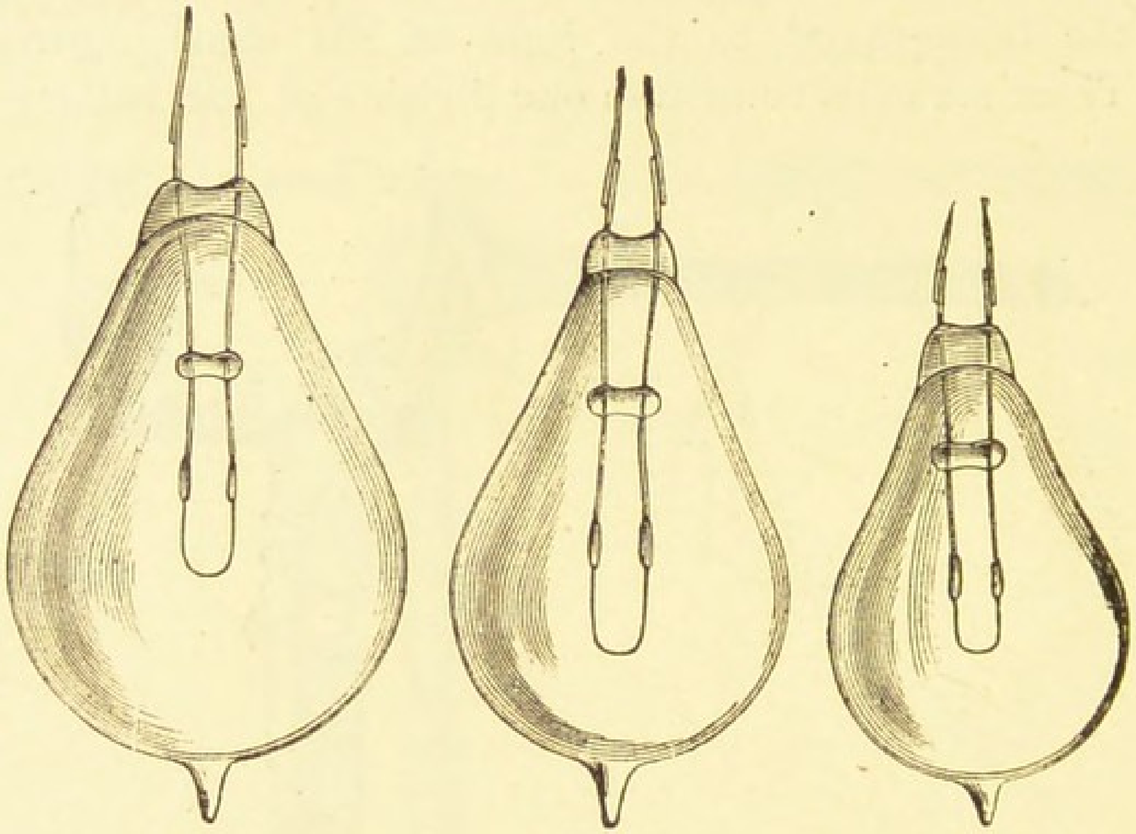


Fig. 59.—Urethroscope ready for use.

The various sized batteries are made up of multiples of these divisions, the 6-cell being but one division, the 12-cell two divisions, and the 18-cell battery three of these divisions. Fig. 63 shows a complete 12-cell battery.

For all classes of work, at least 36 cells will be required. It will be best to make them up of two



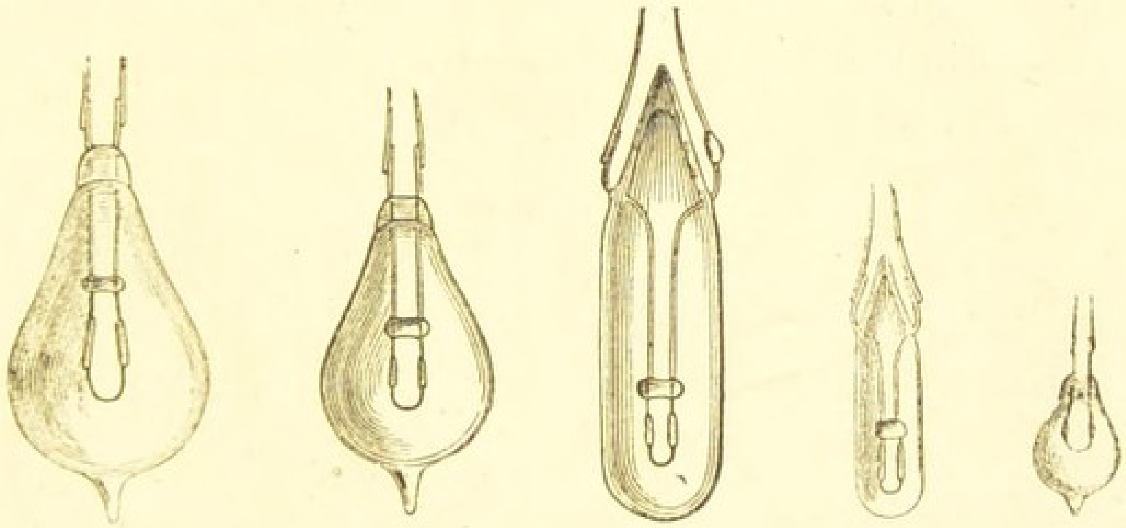
6 Candle. 4 Candle. 3 Candle.

Fig. 60.—Miniature Incandescent Electric Lamps (full size).

Power	6-Candle.	4-Candle.	3-Candle.
Price	$1.50	$1.50	$1.50
Ohms resistance........	6. to 7.	5. to 6.5	3.6 to 4.5
E. M. F. Volts required.	9. to 15.	7. to 8.5	5.5 to 7.
Amperes required	1.4	1.4	1.5

separate batteries of 18 cells each. They can be more conveniently carried about than one large 36 cell battery, and both batteries will not always be required to be carried about.

As an electrolyte for this battery, use "Mason's improved electropoion fluid" to be had of J. H. Mason, 120 Park Avenue, Brooklyn, or of the Empire



1 Candle. ½ Candle. Dental. Surgical. Pea.

Fig. 61.

Power ...	2-Candle	1-Candle	½-Candle	Dental.	Surgical.	Pea.
Price	$1.80	$1.50	$1.50	$1.50	$2.00	$1.75
Ohms resistance.	3.3 to 5.	2.9 to 4.5	1.3 to 2.	1.1 to 3.5	1.7 to 2.5	1.5 to 2.
E. M. F. Volts required	4.5 to 5.5	3. to 5.	2. to 4.	2. to 4.	2. to 2.5	2. to 4.
Amperes requir'd	1.2	1.12	1.3	1.3	1.	1.4

City Electric Co., 15 Dey Street, N. Y. This comes in powder form, and makes ½ gallon, and costs 35cts. per package. With this fluid, there is no residue or crystal formation in the cells, and depolarization is greatly facilitated. Bichromate of *sodium* is far preferable to the potash, as a depolarizing agent for this battery.

The 18-cell battery will weigh about 15 lbs., is 14 inches long, 8¼ inches wide and 7¼ inches high. Less than an 18-cell Galvanic battery will be of little service in medical work, except for cephalic Galvanization and work upon the organs of special sense.

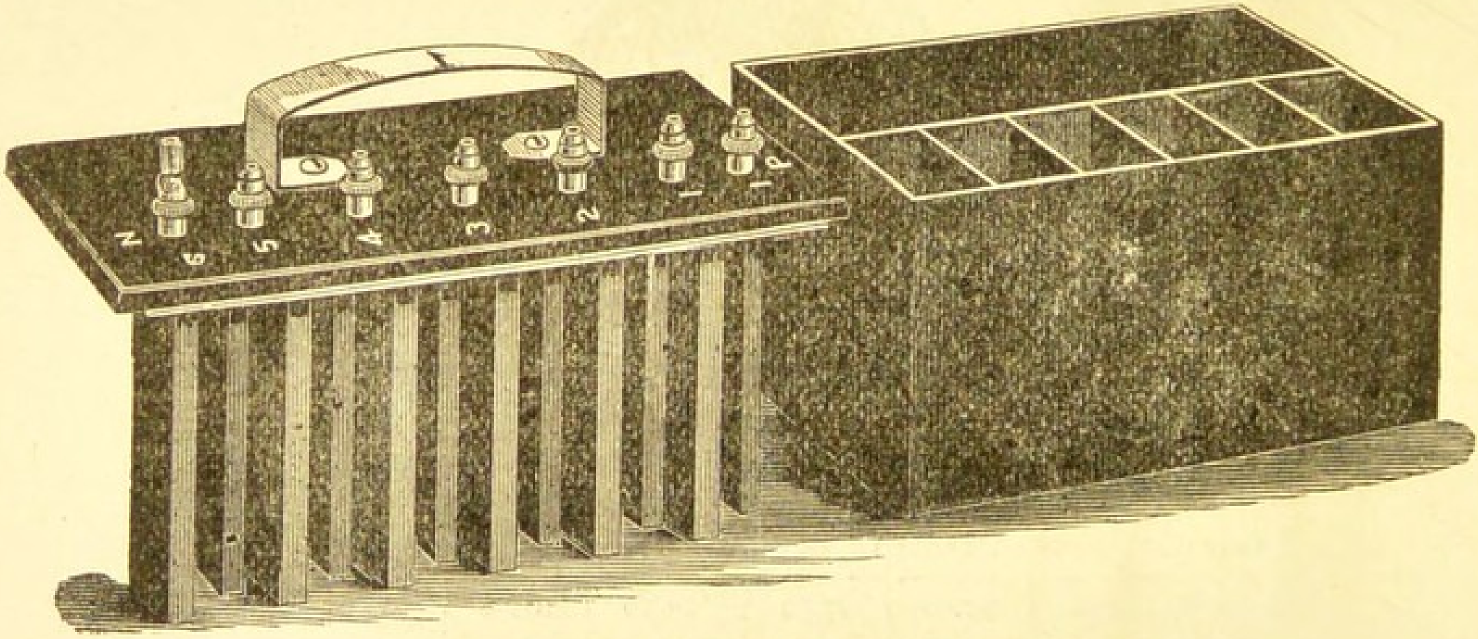


Fig. 62.—The Cells and Elements of the Mc Intosh Battery.

There is no advantage in having a "combined Faradic and Galvanic battery; in fact it is preferable to have them separate and distinct. Waite & Bartlett also make an excellent portable Galvanic battery (Fig. 64.)

A Portable Faradic Battery.—As an emergency battery for use in cases of opium narcosis, postpartum hæmorrhages, etc., there is nothing which surpasses or even equals the Gaiffie pocket battery. One of these should always form a part of a physician's emergency satchel. These are of both American and French make. Demand the French make,

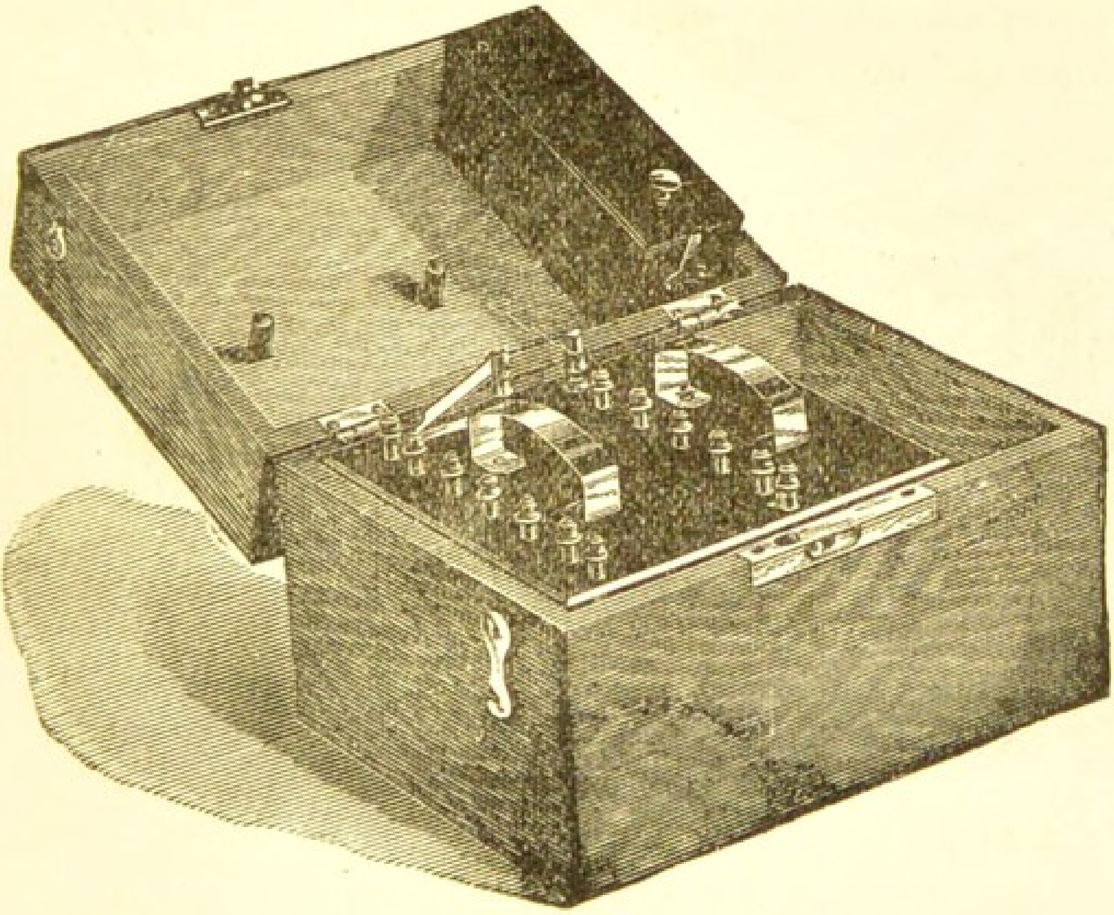


Fig. 63.—The Complete 12-Cell Mc Intosh Portable Galvanic Battery.

and accept none other. As a battery for more accurrate work suited to testing for the "*reactions of degeneration*," the treatment of paralysis, general gynæcological work, etc., the Engelmann Faradic battery will be found to be an admirable one. This battery can be used in the cabinet at the office, and removed from the cabinet for use outside of the office whenever occasion demands. It has three coils—a coarse,

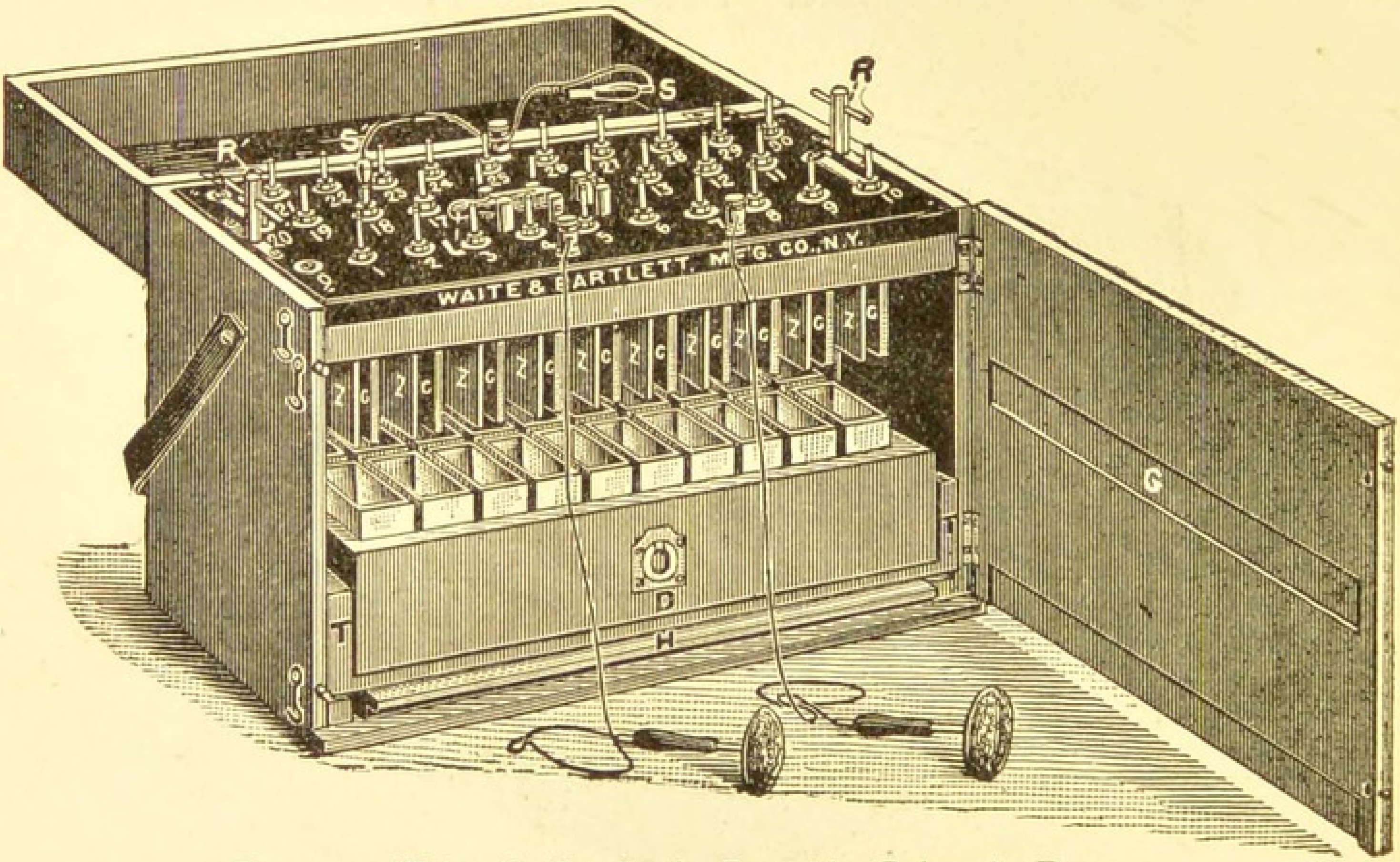


Fig. 64.—Waite & Bartlett's Portable Galvanic Battery.

a medium, and a fine, wire coil—which gives it a wide range of electro-motive force. It has both a slow and rapid interrupter, and a contact key for producing separate impulses. It is manufactured by Waite & Bartlett of 143 East 23rd St., New York City. See Fig. 65.

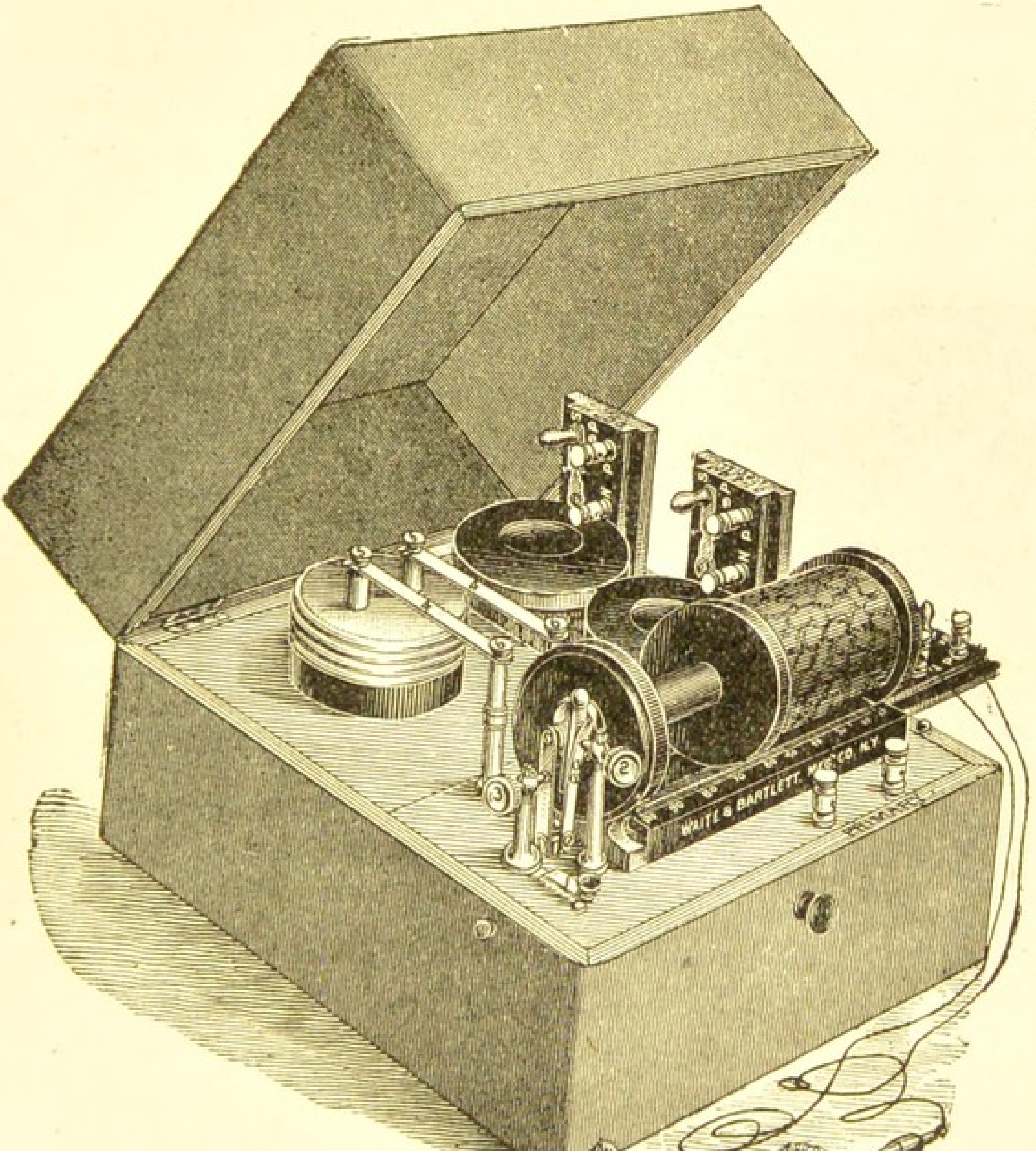


Fig. 65.

Electro-Magnets are principally used for the extraction of particles of iron and steel from the eyes, although they have also been used as therapeutic agents; but we shall not discuss this latter subject in the present book. An excellent eye-magnet is made by Mc Intosh.—See Fig. 66.

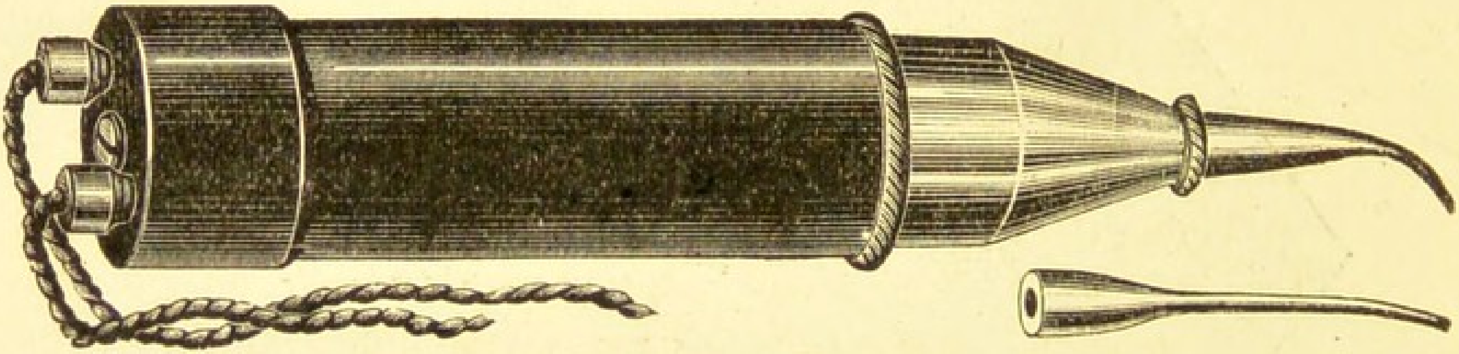


Fig. 66.—The Mc Intosh Eye Magnet.

CHAPTER II.

ELECTRO-PHYSIOLOGY, ELECTRO-CHEMISTRY, ELECTRO-DIAGNOSIS, AND ELECTRO-THERAPY.

ELECTRO-PHYSIOLOGY comprises the study of living tissues as sources of electricity, and also of electricity as a means of influencing organic functions and modifying the excitability of normal organic tissues. The limits of the present work admit only of a brief consideration of the latter phenomena. This property of modifying excitability comprises both *nerves* and *muscles*.

Electro-tonus is the effect produced upon a nerve by the continuous passage of a current of electricity through it. A nerve under the influence of the positive pole, or *anode*, is said to be in an *anelectro-tonic* state, and a nerve under the influence of the negative pole, or *kathode*, is said to be in a *katelectro-tonic* state. Midway between the two electrodes there is a neutral point where the katelectro-tonic state merges into the anelectro-tonic state, and where, therefore, there is no departure from the normal state of the nerve. At the point, or in the part, of the nerve which is under the influence of the anelectro-tonus, the irritability of the nerve is *decreased*, while that part subjected to the katelectro-tonus has its irritability *increased.* Hence it is that the anode is employed to relieve spasm by applying it over the affected nerve, in which the irritability is increased, or for the relief of painful affections, such as neuralgia, by applying it over the affected nerve, in which there is a condition of hyperæsthesia. On the other hand, the kathode is employed to increase irritability in the nerve in certain forms of paralysis, and to stimulate the vasomotor nerves, and thus increase the nutrition of atrophied muscles and other denutrified parts. These observed phenomena constitute a basis for the rational and scientific use of electricity, both as a diagnostic and therapeutic agent.

Normal Reactions.—When a current of electricity is applied to the sciatic *nerve* of a recently killed frog, the leg is jerked both at the making and breaking, or closing and opening, of the circuit. During the *continuous* flow of the current through the *nerve*, however, the muscle, except when the current is very strong, remains quiescent. The *amplitude* or violence of this muscular contraction, increases and diminishes in accordance with each increase and decrease in the *volume* of the current employed. These phenomena are known as the "*reactions*" of a *nerve* to electrical stimulus. The amount of this reaction is further influenced by the rapidity with which the volume of the current flowing through the nerve reaches its maximum. For example, a current which is very gradually brought up to a maximum volume of 5 milli-amperes, produces no contraction, while a current of one-fifth this volume applied suddenly will produce marked contractions. The amplitude of the contractions, or the degree of intensity of the reactions, will depend upon the *pole* which is placed over the nerve, and also upon the question as to whether the electric change in the nerve results from an *opening* or a *closing* of the circuit. For example, place a moderately large moist electrode, connected with the positive pole, to some indifferent part of the body, as, for instance, over the lumbar enlargement; connect the other, or negative pole, to a small moist electrode, and apply this over the peroneal nerve at the head of the fibula. Now determine how many milli-amperes are required to produce the first visible contraction by closing and opening the circuit. Then transpose the poles, and repeat the experiment. The results will prove that a contraction or reaction will be induced with the fewest number of milli-amperes, or with the weakest current, on *closing* the circuit with the *negative* pole (kathode) lying over the nerve. This is called the "*kathodic closure contraction*," and it is symbolically expressed by the formula K C C; 2d, that the next in order will be when the circuit is *closed* and the *positive* pole (anode) is lying over the nerve, called the *anodic closure contraction* (A C C); 3rd, that closely upon its heels or along with it, will be the the contraction induced by *opening* the circuit when the *anode* is lying over the nerve—the *anodic opening con-*

traction (A O C); 4th, that with the strongest current the *kathodic opening contraction* (K O C) will be produced.

K C C will, therefore, be strong when it is obtained with the volume of current necessary to excite an A C C or A O C; and very strong with that necessary to excite a K O C. The natural sequence, thus, of the normal electrical reaction is:

K. C. C..	weakest current.
A. C. C. } A. O. C. }	medium "
K. O. C.....	strong "

When the electrodes are applied as above, the number of milli-amperes which will ordinarily be required to produce the first perceptable contractions under these various conditions are:

K. C. C.............	5 milli-amperes.
A. C. C.............	12 " "
A. O. C.............	26 " "

It is important to remember the general *relationship* of these values (not the values themselves, for they will vary slightly with different subjects) since this normal relationship is changed in certain pathological conditions, and hence it is valuable as an aid to diagnosis and prognosis.

It must be remembered that it is the *density of the current in the nerve* which determines the amount of excitement, and not alone the volume of the current as registered by the milli-ampere meter, and that this *density in the nerve* is controlled by the *size* of the active electrode and the *location* of the two electrodes.

Hence it is just as important to pay attention to, and record, the size of the electrodes and their location, as it is to note the strength of the current. A current of one milli-ampere flowing from an electrode having an active surface area of one square inch, will have a density ten times as great as the same volume of current flowing from an electrode having an active surface of ten square inches. The density should be represented by a fraction, in which the value of the volume of the current occupies the position above the line, and the value of the active surface area in square inches or square centimeters occupies the position below the line, thus:

$$\frac{\text{Volume of current (in milli-amperes).}}{\text{Surface area (in square inches or centimeters).}}$$

If we send a current of one milli-ampere through electrodes having a surface area of 1, 2, and 10 square centimetres respectively, the densities of these several currents will be expressed by the fractions $\frac{1}{1}$, $\frac{1}{2}$, and $\frac{1}{10}$; and it is evident that whilst in the first case one milli-ampere will pass through 1 sq. c. m., only .5, .2 and .1 milli-ampere will pass through the same area in the case of the other electrodes. Hence, the density, which determines the amount of the chemical and physiological action of the current in the part of the body under the electrode, diminishes as the size of the latter is increased.

There is no advantage in placing the two electrodes on the skin along the course of the nerve. It is a prevalent fallacy to suppose that the *direction* of the current in the nerve exerts any special influence. In other words, it is a matter of indifference whether the current flows in the same direction as the normal nerve impulse, or in the opposite direction; so that it matters not where the "*indifferent*" electrode lies with reference to the "*testing*" electrode; it may be placed above, below, or opposite. So much for the action of the *Galvanic* current on a motor nerve.

If an "induced" current from an induction coil be applied to a motor nerve, we get a persistent "tetanic" contraction of all the muscles supplied by that nerve, instead of separate, distinct contractions. This results from the fact that the induced current is made up of a series of very short impulses, each of which acts as a Galvanic "*make*" excitation; and the "*tetanus*" is due to the fact that each successive stimulation resulting from the rapid impulses falls upon the nerve before the muscle has reached its maximum contraction and had time to relax, thus impressing a fresh stimulus upon the muscle in time to prevent its relaxation.

Healthy voluntary *muscles*, when *directly* stimulated by the Galvanic and Faradic currents, are influenced by the same conditions, and follow the same laws governing the application of these currents to motor nerves.

Each muscle has a certain "point" or points where, if the current is applied, it reacts more readily. These are called the "*motor points*," and their location for each muscle of the body must be carefully studied. Ziemmsen has investigated this question thoroughly, and proved that such points correspond to the spot where the motor nerve enters the muscle, and he has made admirable charts showing their location. When a current is directly applied to a muscle, it alone contracts; but when the current is applied to the course of a motor nerve, all of the muscles supplied by it contract. Muscles contract more easily when they are relaxed.

Involuntary muscles, instead of contracting suddenly when a Galvanic current is set up in them, and subsequently relaxing, contract slowly and continue contracting so long as the current flows, and even after it ceases. When the current is applied to the viscera, all involuntary fibres can be made to contract. When applied to the abdominal viscera of the living being, peristaltic action of the intestines is induced.

Sensory nerves give *sensory* reactions in the same manner and order that motor nerves give motor reactions, and follow the same laws with respect to the poles, etc.

ELECTRO-CHEMISTRY.—*Katalysis* is the term applied to indicate the *inter-polar* chemical action that occurs when a continuous Galvanic current is passed through organic tissues. This action can be demonstrated by simply passing a current through water, when it will be decomposed into its component parts —hydrogen and oxygen; the hydrogen and any alkalies that it may contain going to the negative, and the oxygen and any acids going to the positive, pole. The same action takes place on passing a current through organic tissues, all the tissues lying between the poles being subjected to this catalytic action, as it is called.

Electrolysis, on the other hand, is a term applied to the local, or *polar*, chemical action that occurs in the tissues immediately around either one, or both, of the electrodes. In this case we have, in addition to the inter-polar disintegrating and absorbing process, a local effect of peculiar and varying character around each electrode, according to the pole used, the tissues acted upon, and, in the case of the positive pole, the material composing the electrode. If the positive pole is composed of ordinary steel, the acids which accumulate around this pole will oxidize the steel, and cause the surrounding tissues to stick to it, so that portions of the tissue may be torn away with the removal of the pole. Hence, positive electrodes designed for electrolytic use should generally be made of either gold or platinum.* The positive pole is the

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*Dr. Goelet has, however, recently devised electrodes made of steel, treated in a peculiar way (de-hydrogenized), which does not oxidize under the action of the positive pole. They are manufactured by Waite & Bartlett. See Fig. 67.

more caustic and hæmostatic of the two, while the negative is the more destructive of tissue. For this reason we use the positive pole as the active internal electrode in the treatment of hæmorrhagic fibroids of the uterus, and in hæmorrhagic and leucorrhœal metritis and endometritis. The negative pole, however, being more destructive of tissue, and katelectrotonic in its action upon the vaso-motor nerves, is generally employed in the non-hæmorrhagic variety of fibroids, and in simple hyperplasia.

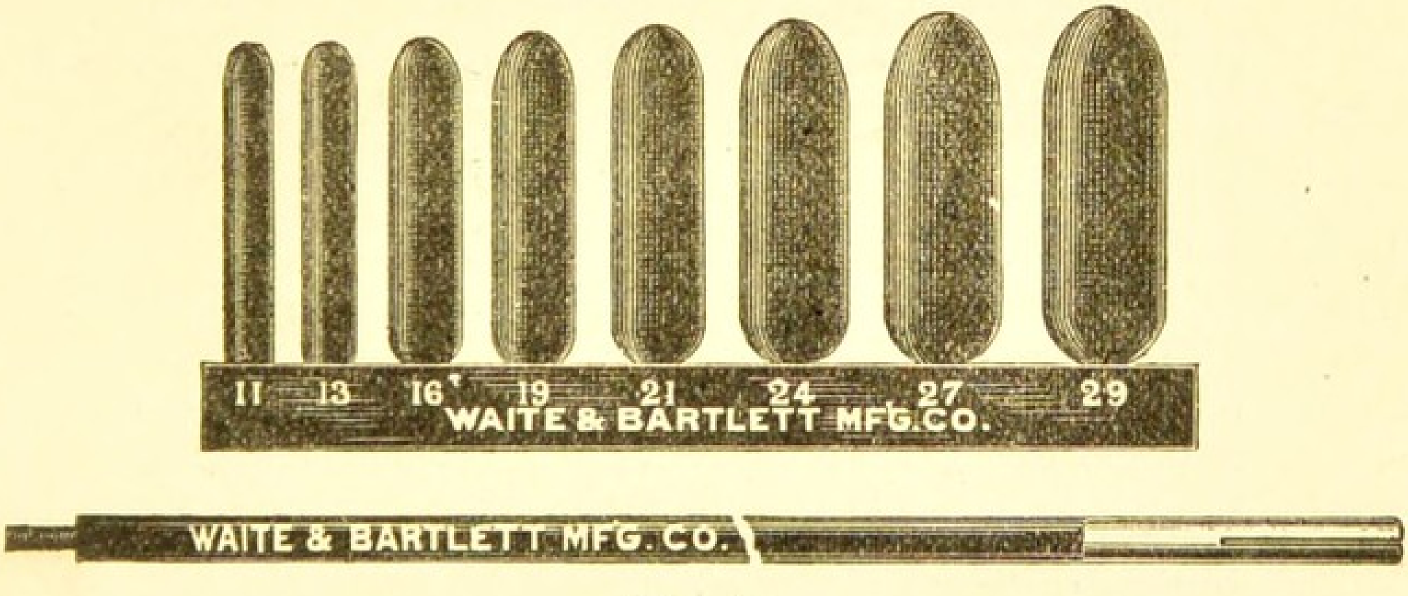

Fig. 67.

Kataphoresis, is the term applied to the movements of liquids or solutions from one electrode to the other, through animal tissues, under the influence of a Galvanic current. Munk, Von Bruns, and Adamkiewicz, were the first to demonstrate this osmotic action of the Galvanic current. They successively transmitted solutions of quinine, iodide of potassium, and chloroform through the skin. In this way strychnine, cocaine, bichloride of mercury, and in fact, most any soluble drug, can be passed into the body at any point. The drug should, as a rule, be placed upon the anode, and this applied to the point it is desired to medicate; but if the special action of the kathode is desired, this pole should be placed over the affected part, the medicine heing applied to the anode. Whenever the anode is employed for the relief of pain, the efficacy is enhanced by moistening it with a ten to twenty per cent. solution of cocaine. The skin should be rubbed with a little alcohol or chloroform, before Galvanization, in order to remove all oil globules. With either cocaine or aconitine, or both combined, deep local anæsthesia may be produced sufficient for the relief of pain, or to admit of the painless performance of small operations. Anodic electrolysis in conjunction with cocaine kataphoresis, gives great relief in neuralgias and other localized painful affections. Drs. Richardson, Wagner, Adamkiewicz, Corning, and Peterson, have been largely instrumental in bringing this phenomenon of Galvanic narcotism or anæsthesia prominently before the profession.*

Absorption, is increased by the Galvanic current.

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*The Peterson electrode, made by Waite & Bartlett, will be found to be the best electrode for kataphoric purposes. All such electrodes should be made of carbon covered with some absorbent material.

The tissues and fluids which the current has decomposed are absorbed, and the natural absorption is increased; the blood-vessels and lymphatics are dilated, and the circulation of the blood and nutritive fluids is increased.

Increased Nutrition, therefore, results from the passage of a Galvanic current. This naturally arises from the increased supply of nutritious fluids. The Faradic current produces a similar effect mechanically, but not to the same extent. This effect of the Galvanic current has been very beautifully and thoroughly demonstrated by Prof. Thatcher, of Yale College, by applying the current for a week at a time alternately to the two arms of a person afflicted with paralysis, and measuring the strength of the hands at the end of each week by means of a dynamometer. It was thus demonstrated that the power increased much more rapidly in the Galvanized arm. The folfowing is a tabulated showing of the result:

	Galvanized Arm.	Untreated Arm.
(1) Gain in strength first week (left).	17°	12°
(2) Gain in strength second week (right).....................	15°	10°
(3) Gain in strength third week (left)	7.4°	0.9°
Total.....................	39.4°	22.9°

Showing that the Galvanized arm made almost double the progress of the other (1:1.72) The same person showed no evidence of gain from Faradism or massage.

Electro-Diagnosis, is based upon the comparison of the electrical reactions known to exist in the normal state, with those found in abnormal conditions of the nerves and muscles. Electricity in many cases affords a ready means of diagnosing structural changes, of locating pathological lesions, and of differentiating between real and simulated affections. The localization of brain functions owes its origin to electricity.

The Reaction of Degeneration (R. D.), consist of two kinds of changes: First, *quantitative*: Second, *qualitative*. The first, consists of either an increase or a diminution of the electrical excitability of motor nerves and muscles, the same being manifested by the nerve or muscle reacting to a current of less strength than in the normal state, or by contracting violently under a current which would in the normal state only produce slight contractions. The second, consists of a change in the *character* of the contractions, and also a change in the *serial* order of the "normal reactions." For instance, instead of the short, quick contractions of health, we may find the contractions slow and prolonged, which is known as a "*modal*" change, and again, the normal law of reaction to the Galvanic current is changed so that instead of kathodal closure (K. C) producing contraction with the weakest current, anodal closure (A. C.) may do so, or the two may each produce an equal contraction with the same current; or anodal opening (A. O.)

may produce a contraction before anodal closure (A. C.); all of which are known as "*serial*" changes.

Reaction of Degeneration (R. D.) *in Nerves*, consists of a quantitative diminution to both Galvanic and Faradic currents, apppearing alike, either rapidly or slowly, according to the acute or chronic character of the disease, with perhaps a final complete loss.

Rarely is there any qualitative change, and whenever there is, it is generally a modal one.

Reaction of Degeneration (R. D.) *in Muscles*, consist of both quantitative and qualitative change in the reactions of both the Galvanic and Faradic currents.

If the Faradic current is applied directly to a muscle, the latter contracts by reason of a stimulation of the intra-muscular nerve fibres, the muscular fibres not being affected directly by currents of so short a duration. The Faradic current, therefore, follows precisely the same course when applied to a muscle that it does when applied to a nerve, and the disappearance of Farado-muscular excitability is synchronous with, and dependent upon, degeneration of the intra-muscular nerve elements. Galvano-muscular excitation, on the other hand, produces very characteristic phenomena. If the morbid process be acute, there is at first a slight diminution (*quantitative* change) in response, soon followed by an increase. This peculiarity is very characteristic of facial paralysis of rheumatic origin, and in peripheral traumatic paralysis. In such cases the rise begins during the second week, rapidly reaching a point where the weakest Galvanic current is sufficient to excite the muscle. This hyper-excitability persists for several weeks, gradually sinking back to normal or sub-normal, according to the extent of the nutritive change in the muscle. In chronic cases, the diminution is the only observable quantitative alteration. The *qualitative* changes which simulaneously exist are both *modal* and *serial* in character. In many cases the sluggish, protracted, contraction wave indicative of a modal change, is the only ground upon which to diagnose reaction of degeneration. The serial changes consist principally in the overtaking of KCC by the ACC.

What, then, does reaction of degeneration signify; and what are the pathological conditions to which it corresponds? Those who undertake the practice of electro-therapy should have perfectly clear ideas concerning these points. Reaction of degeneration depends upon a specific histological modification of the irritable tissues, called "degenerative atrophy," and this degeneration itself is due to an interference with, or a stoppage of, the peculiar influence of the grey matter upon the nerves and muscles, known as the "trophic" influence. When R. D. occurs, either complete or partial, we therefore conclude that an alteration exists either of the centres themselves, or of the channels (motor fibres) which convey their influence. Erb has constructed some very instructive curves illustrative of this relationship between the reaction of degeneration, and the histological changes accompanying it.

These are in brief the main facts which constitute the underlying principles of electro-diagnosis.

The table, page 102, compiled from Erb, gives a general idea of the connection between certain pathological states and the electro-diagnostic phenomena accompanying them.

ELECTRO-THERAPY.—The general proposition that electricity, intelligently applied, is a valuable palliative, and in many cases a curative agent in the treatment of numerous morbid processes, requires no argument at this period. The only question is, how shall it be rationally and scientifically applied? This is accomplished by bearing in mind:

1st. Its property of conveying liquids from pole to pole through the tissues, or kataphoresis and osmosis:

2nd. Its property of inducing chemical changes in solutions through which it circulates, or katalysis:

3rd. Its polar chemical effect, or electrolysis:

4th. Its effects upon the circulation of lymph and blood through the tissues, directly by exciting the vessels themselves, indirectly by exciting vaso-motor and sympathetic nerves, and reflexly by exciting sensory nerves.

The Direction of the Current, may be either

SEAT OF LESION.	PROMINENT SYMPTOMS.	ELECTRICAL REACTIONS.	PATHOLOGICAL CONDITIONS AND THEIR LOCATION.
Path of impulse from the brain (antero-lateral columns); or the brain itself.	Paralysis. No muscular degeneration.	All normal.	Lateral sclerosis (idiopathic or from cerebral disease).
"Trophic centre" for the muscle, and also the path of impulse from the brain (antero-lateral columns).	Paralysis. Muscular degeneration.	*Nerve:*—Normal. *Muscle:* — Qualitative and quantitative alterations (Partial R. D.).	Amyotrophic lateral sclerosis.
"Trophic centre" extending to multipolar ganglion-cell of the anterior horn of grey matter.	No paralysis at first. Muscular (afterwards nervous) degeneration.	*Nerve:*—At first normal; afterwards diminished. *Muscle:* — Qualitative and quantitative alterations (Partial R. D.).	Progressive muscular atrophy (of central origin). Bulbar paralysis. Mild acute poliomyelitis.
Multipolar ganglion-cell of the anterior horn of the grey matter.	Paralysis. Atrophy of muscles and nerves. Abolition of reflex actions.	*Nerve:* } Reaction of de- *Muscle:* } generation.	Anterior poliomyelitis. Infantile or spinal paralysis. Lead poisoning.
Motor nerve-fibre.	Paralysis. No degeneration.	All normal.	*Light* form of "rheumatic" "traumatic," or "pressure" paralysis.
Motor nerve-fibre and path of trophic influence to the muscle.	Paralysis. Muscular degeneration.	*Nerve:*—Normal. *Muscle:* — Qualitative and quantitative alterations (Partial R. D.).	*Middle* form of ditto.
Motor nerve-fibre, path of trophic influence to *muscle*, and path of trophic influence to *nerve*.	Paralysis. Muscular and nervous degeneration.	*Nerve:* } Reaction of de- *Muscle:* } generation.	*Severe* form of ditto.
Muscular fibre.	Pseudo-paresis. Simple atrophy.	Normal, or diminution to maximal excitations.	Muscular wasting in phthisis, etc.; and in diseases of the joints. Idiopathic myositis?

"*descending*" or "*ascending*," according as it flows with or against the natural volitional impulse in motor nerves. The weight of authority has in the past ascribed the exciting or depressing effect of an electrization of a nerve to the direction of the current. This theory is, however, a thing of the past, for we now know that the direction of the current has nothing to do with determining the katelectro-tonic or anelectro-tonic influence of a current, and that this is determined alone by the pole employed as the active electrode.

The Choice of Pole, should depend upon the effect desired; as a rule applying the positive pole to those parts requiring an anodyne or sedative effect; and the negative where an excitant is needed, and in all cases where the *electro-tonic* action of the current is alone sought for. Bearing in mind, however, that wherever the expected results do not follow the use of the theoretically indicated pole, the contrary pole should be tried; and that the *katalytic* influence of a current is oftener of more importance therapeutically than its *electro-tonic* action, and that wherever this catalytic action is most promising, the alternate influence of both poles upon the affected part is indicated, not by sudden reversals of the current (*Galvanic alternations*), however, but by the gradual removal of one pole, and a gradual application of the other. In many cases the choice of pole is determined by special indications, such as the hæmostatic or styptic, and the Galvano-caustic, effect of the positive pole, in the electrolytic treatment of certain hæmorrhagic forms of endometritis, etc. The position of the poles should, however, be determined equally as much by physical indications, so as to secure the most complete permeation of the organ or tissues, for it must be remembered that the most important point is to reach the organ with a current of the desired density.

The Choice of Current, should depend upon whether it is desired to secure a mechanical or a chemical effect. Mechanical effects are dependent upon the rate of electric change in the motor nerve, rather than upon the volume of current in the nerve, and, therefore, because of its intermittent character, the Faradic current, is best suited for the production of mechanical effects, such as the contraction of muscles and muscular tissues; while chemical effects are dependent upon the volume of the current flowing through the tissues, rather than upon the rate of change, and, therefore, the Galvanic current, because of its constancy, is best suited for the production of chemical changes, such as accompany catalytic, electrolytic, and electrophoric actions.

Not, however, because there is any inherent difference in the two currents, but simply because of the different physical conditions under which they appear, the one being *constant*, and the other *intermittent*. By using a Galvanic current of small volume and high electro-motive force, and interrupting it with sufficient rapidity, effects may be produced identical with those of Faradism; but the latter has the advantage of being generated by a much more compact and simple device.

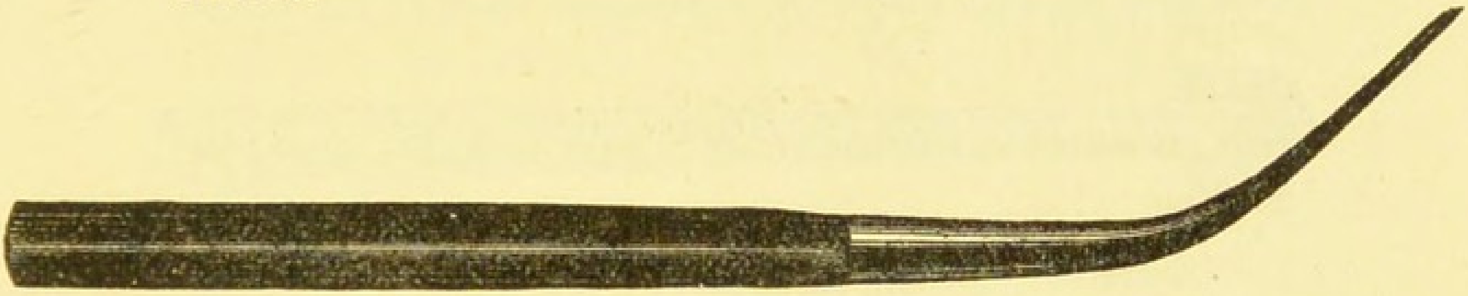

Fig. 68.—Pointed Electrode.—For use in connection with Electro-static Induction Machines.

The greater the rate of electric change or rise and fall of potential, and the smaller the volume of the current, the less will be the pain with equal degrees of muscular contraction. Hence it is that direct intermittent, or induced intermittent, cur-

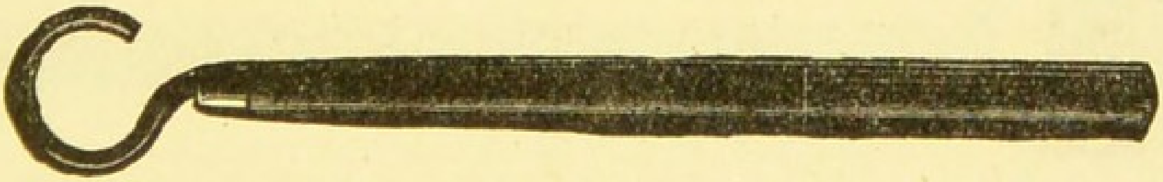

Fig. 69.—Electrophore Holder.—For use in connection with Electro-static Induction Machines.

rents of small volume and high potential, derived from electro-static induction machines, will induce more muscular contraction with less pain than even Faradic currents. The necessary electrodes and accessory implements for the application of these currents are illustrated in Figs. 68 to 73. The method of applying the direct intermittent current by means of the Morton electrode-handle, manufactured by McIntosh, of Chicago, is illustrated in Fig. 74. Waite and Bartlett, of New York, manufacture uterine, urethral, vaginal, rectal, and other useful special electrodes for this handle, and they also make one form of the latter,

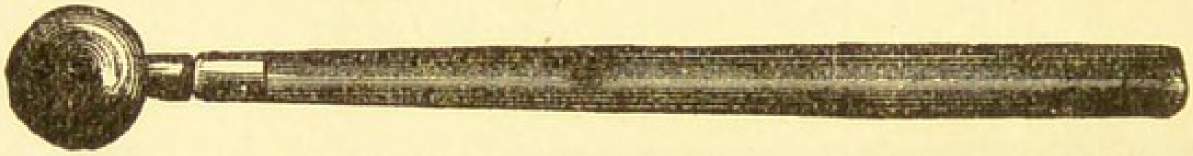

Fig. 70 —Ball Electrode.—For use in connection with Electro-static Induction Machines.

shown in Fig. 73. But the author does not like it as well as the one shown in Fig. 72. For per-cutaneous electrizations, where only superficial muscles are to be affected, the uncovered dry electrode will answer; but where deep muscles are to be reached, the electrode should be covered with a moistened covering The

Fig. 71.—Roller Electrode.—For use in connection with Electro-static Induction Machines.

method of applying the induced intermittent current from electro-static machines, is illustrated in Fig. 75. In both these methods the current is regulated by changing the distance between, in the first case, the balls upon the handle, and in the second case, the balls upon the inductors of the machine. There is practically no difference in the two methods. In all vaso-motor disturbances, functional cerebro-spinal diseases or neuroses, there is nothing in the author's experience which equals in value the diffused and the concentrated constant high-potential currents from electro-static induction machines. The method of applying the *diffused* constant current is shown in

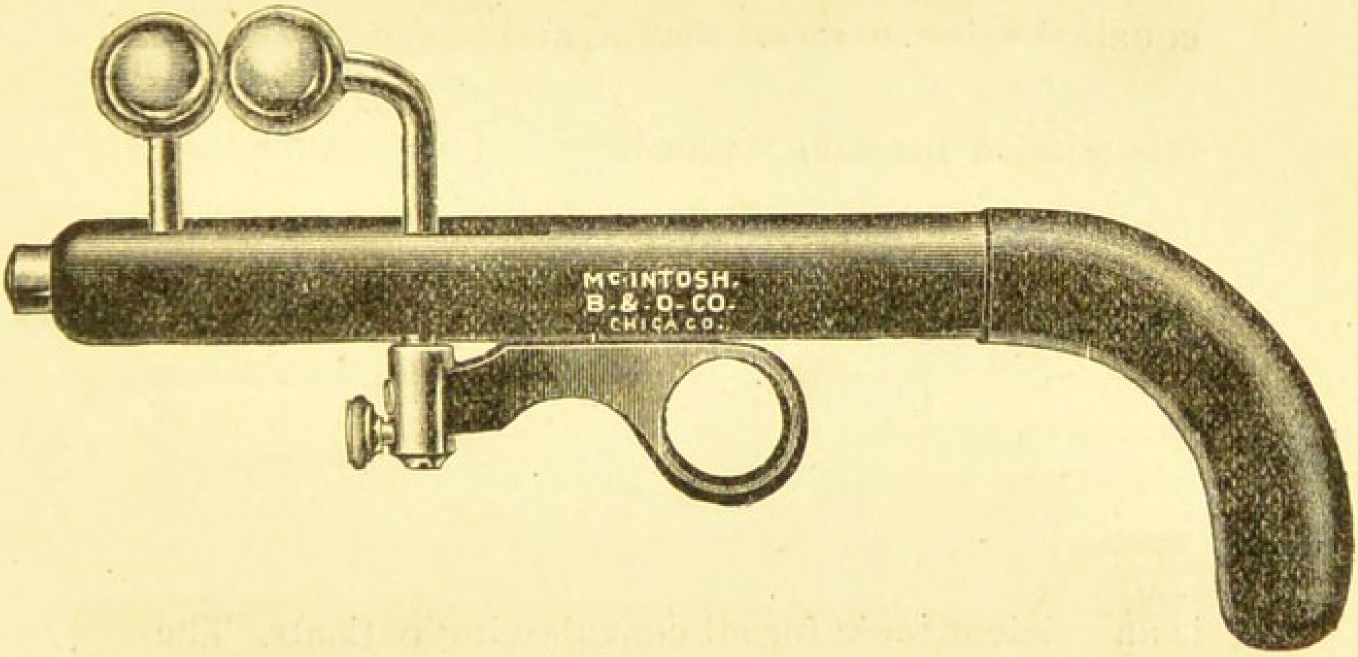

Fig. 72.—Morton's Electrode Handle.—For use in connection with Electro-static Induction Machines.

Fig. 76, and the method of applying the *concentrated* constant current is shown in Fig. 77. In the former case, the circuit is completed at all parts of the body, through the air. In the latter case, the circuit is completed by concentrating the current upon some particular part of the body by means of a spray coming from the pointed electrode shown in the illustration.

The latter method is invaluable as a general vaso-motor tonic and stimulant, as a means of restoring lost vaso-motor equilibrium, of increasing the appetite, and promoting sleep. An ordinary functional head-ache resulting from deficient vaso-motor tonus, or loss of equilibrium, may be relieved by this current in from two to three minutes. It is also of great and un-equalled value in menorrhagia, and in suppression of the menses from cold, or shock of any kind; in muscular rheumatism, hysteria, spinal hyperæmia; and

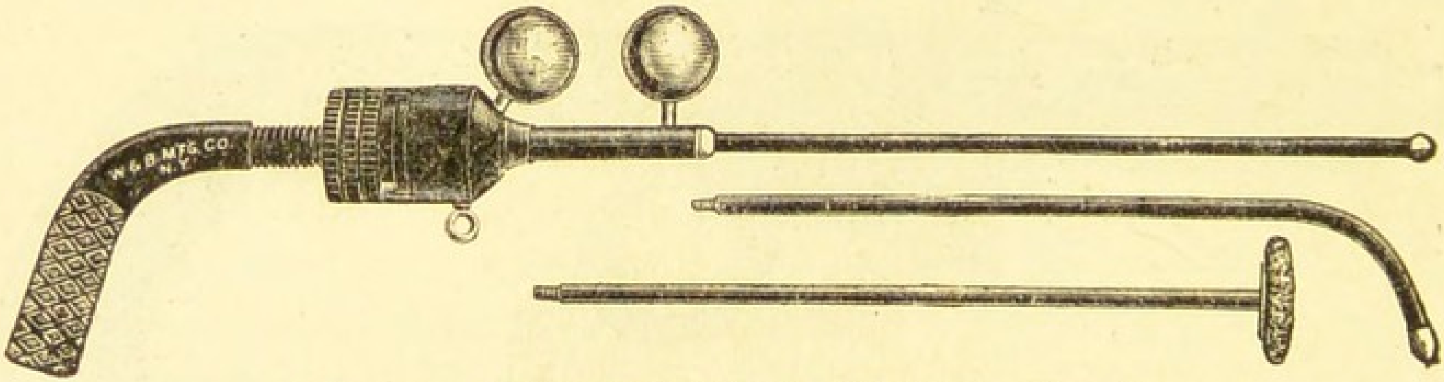

Fig. 73.—Waite & Bartlett's Electrode Handle.

is an efficient tonic for all convalescing patients. The writer wishes to place himself on record as positively denying the correctness of the recent statements of Dr. M. Allan Starr regarding the valueless character of such currents. Dr. Starr's statements are all based upon erroneous premises regarding electro-physical laws, and are unquestionably contrary to the well established clinical observations of the writer of this book, and of scores of other practical workmen in the field.

Dosage.—The usual method of prescribing a current of a certain number of cells, is wholly unreliable and meaningless, and should never be resorted to. Coulombmeters, volt-meters, and milli-ammeters, should take its place. It must be borne in mind that a weak current applied for a comparatively long time, behaves quite different from a stronger current applied for a short time.

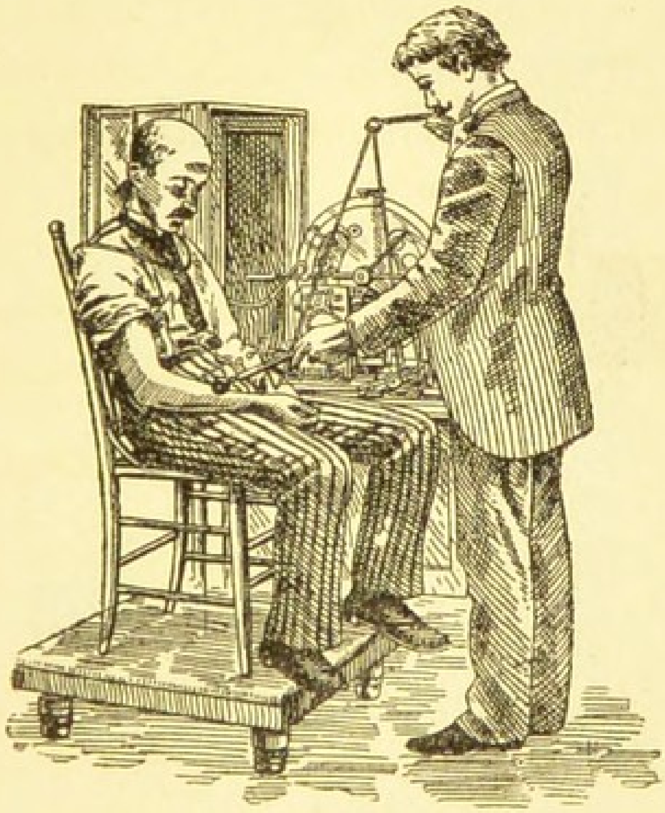

Fig. 74.

Choice and Position of Electrodes.—The size and position of electrodes are essential factors. Electricity is not a fluid to be poured into the body like so much medicine, but, on the contrary, a physical and chemical *influence* that is to be exerted with a *definite intensity* upon some *definite part* of the body.

Were it not so, we might apply it in the form of the charlatanic Galvanic bath. The action of any current is, however, determined by its *density*, so that there is no more resemblance between its effects when distributed over the whole surface of the body, and when applied to a limited area, then between the

Fig. 75.

effects of a certain amount of heat diluted by the water of a bath, and the same amount of heat concentrated upon a definite region by means of a poultice or a red-hot iron. Hence the main physical conditions to be fulfilled are:

1st. That the current be of the required density, this being regulated by the size of the electrodes:

2d. That the electrodes be so placed that the desired density of current will traverse the tissues or organs to be electrized.

Electrization. – It is not "electricity" that cures, but rather, skillful "electrization," *i. e.*, the intelligent and skillful application of electricity. To say that "electricity is good" for this, that, or the

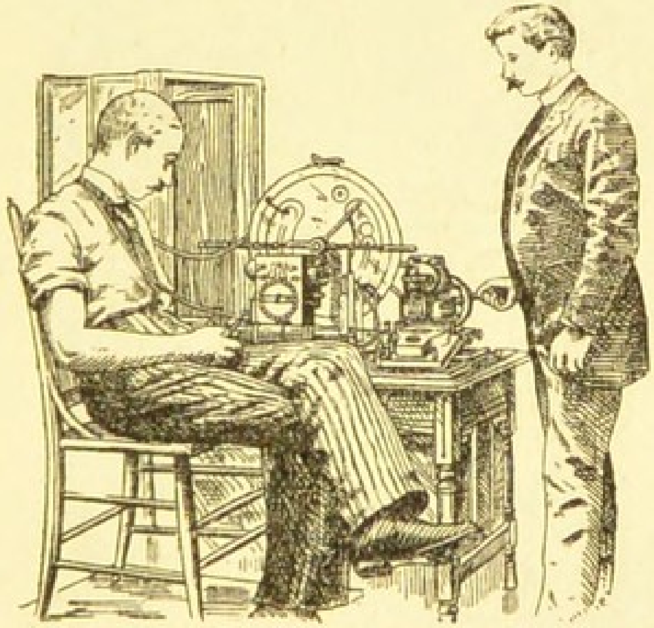

Fig. 76.

other, malady, is equivalent to saying that "medicine" is good, or that "water" is good, without specifying what kind of medicine and in what dose, or whether the water should be hot or cold, in the form of ice or steam, or applied externally or internally; for the soothing action of chloral and the exciting action of strychnine, or the soothing action of a hot bath and the exciting action of a cold douche, differ about as much as the sedative influence of a mild continuous

Galvanic current differs from the stimulating effect of an interrupted or Faradic current; the one may be beneficial where the other may be harmful. Painful currents, as a rule, do more harm than good. At the beginning of a course of treatment, great caution must be exercised in order to avoid too strong a cur-

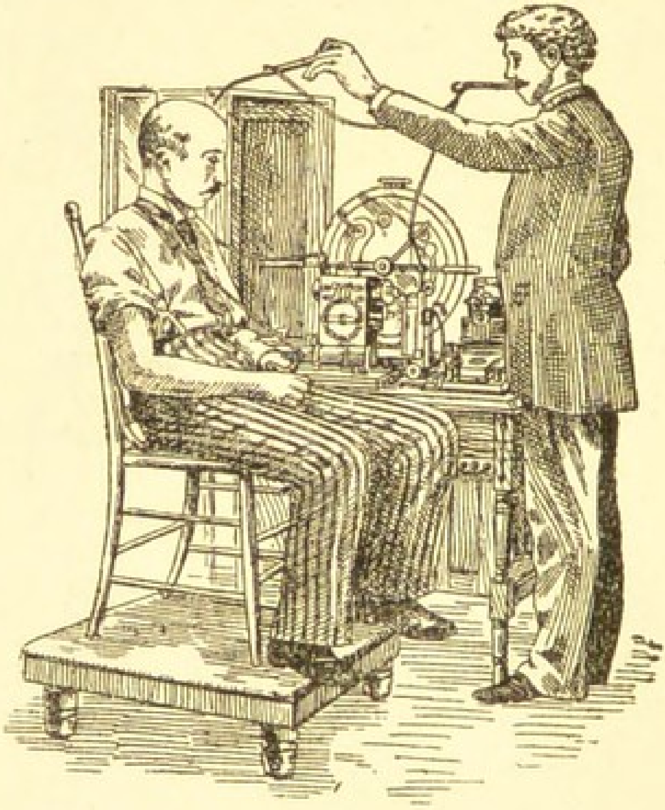

Fig. 77.

rent. Anxiety to cure may frequently tempt one to err in this direction. Nothing general can be said as to the frequency of the electrizations. In determining the points to be electrized, the seat of the lesion and the location of the symptoms must both be considered, and the one may require a very different form of current from the other. In certain constitutional diseases, or when there exists a general vital depression of nervous or other origin, it is often useful to bring the whole, or the greater part, of the body under electrical influence.

In commencing a course of treatment, and at different times thereafter, particularly in all cases of paralysis, it is very desirable to have at hand a ready means of taking a photograph of the patient, and of

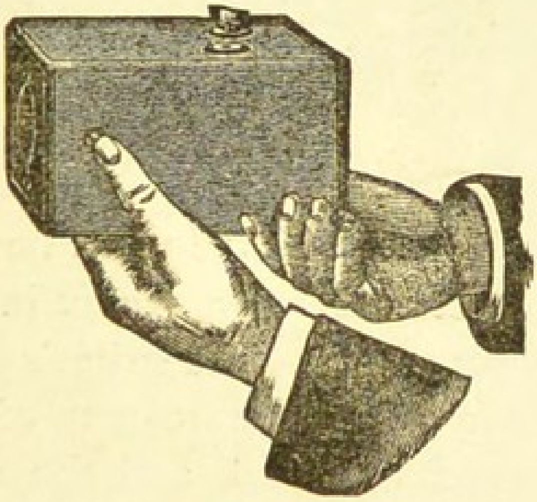

FIG. 78.

the parts affected, both while in their normal condition and when reacting under the influence of the different currents, thus enabling us to more thoroughly study, record, and publish, the results of such treatment. The writer has found this to be best accomplished by the No. 64 "Kodak" illustrated in Fig. 78. To operate it, requires no special skill. It is a magazine instantaneous camera, which will take one hundred pictures without reloading. A picture is taken by simply pointing the camera and pressing a button, as shown in Fig. 79; the manufacturers of the camera do the rest. In the localization of lesions of the brain, such a device is of great value.

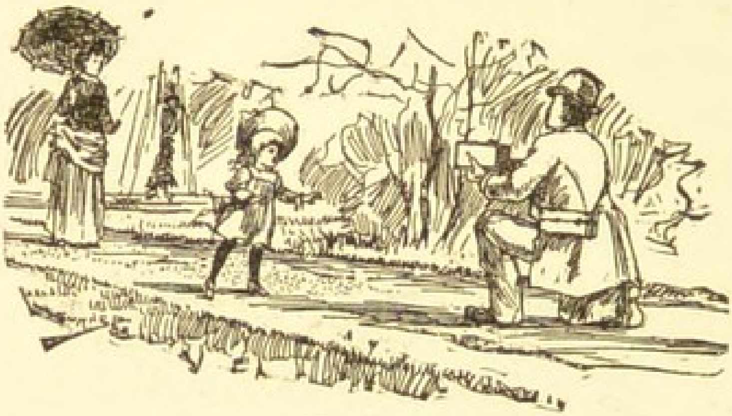

FIG. 79.

There has been no effort in this book to deal with the subject of electro-therapy, except in the most general and cursory manner. The writer's only object has been to present a correct statement of the principal physical problems involved, and the apparatus employed, in the modern practice of electro-therapeutics.

The author expects soon to write another book, devoted exclusively to electro-therapy, both general and special.

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