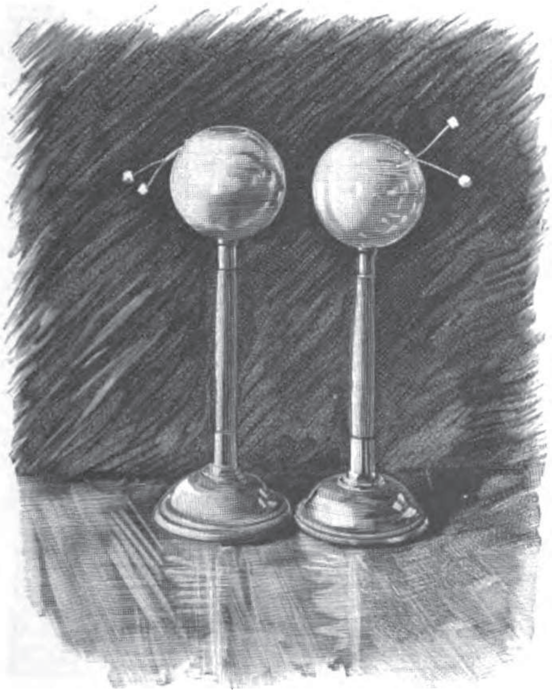
SCRIBNER'S MAGAZINE.

VOL. V. JUNE, 1889. No. 6.

ELECTRICITY IN THE SERVICE OF MAN.

AN INTRODUCTORY PAPER.

By C. F. Brackett.



Insulated Metallic Spheres, showing inductive action.

ELECTRICAL phenomena have now come to be such important factors in the daily administration of human affairs that the age in which we are living may, with a certain propriety, be called the age of electricity, just as former ones have been called, respectively, the ages of stone, bronze, and iron.

It may be taken for granted that the curiosity or interest of every reader of this Magazine will prompt him to inquire, if he has not already done so, how the mysterious agent which we call electricity is brought under control and directed so as to perform the almost infinitely varied service which is now exacted of it. In fact, almost every industry and art is either so dependent upon, or influenced by, its application that no one, whatever his pursuit, can ignore them and yet hope to attain a foremost place.

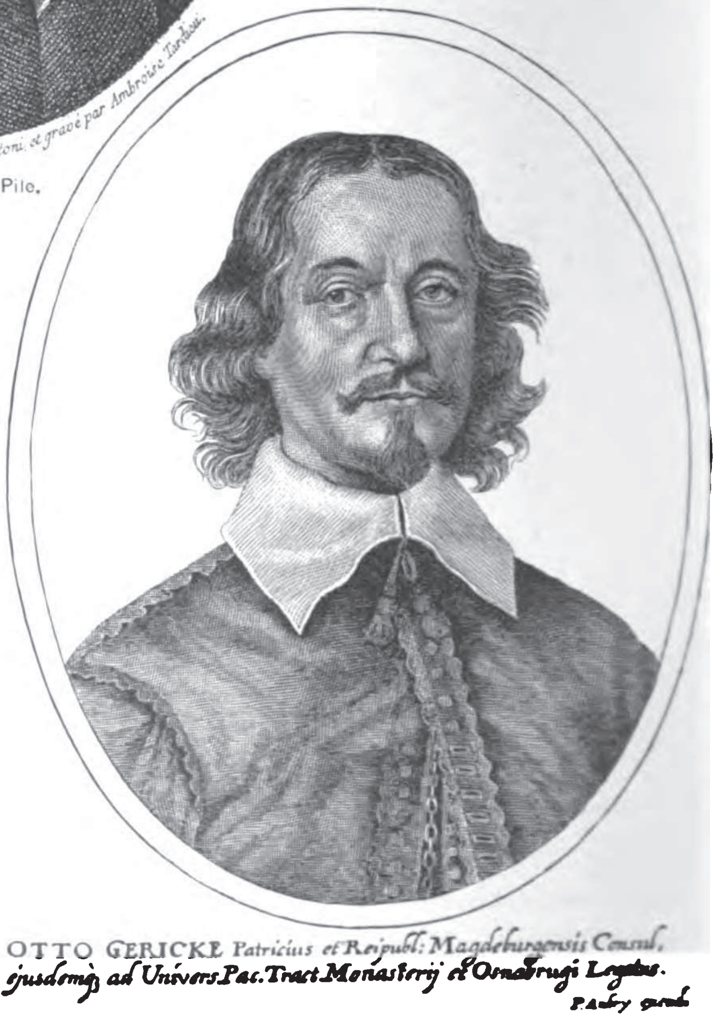
It is the purpose of this article to set forth, in a general way, some of the common methods in accordance with which the more important electrical phenomena are produced, the laws which these phenomena reveal, and the principles involved in the measurement of electrical quantities. What I shall have to say will be concerning principles which will be fully applied in the course of articles which are to follow.

The term *electrical* was first employed in 1600, by Dr. Gilbert, to designate the attraction which amber (ἤλεκτρον), and other substances of its class, exhibit when rubbed and presented to light bodies, such as bits of pith or paper. This term and its corresponding substantive have been everywhere adopted in reference to the phenomena we are about to consider.

If a piece of amber, or resin, and a piece of glass be rubbed together and then separated, they are no longer indifferent to each other as before, but each attracts the other. In this condition the bodies are both said to be *electrified*, or *charged* with electricity. Evidence of this condition is easily secured by

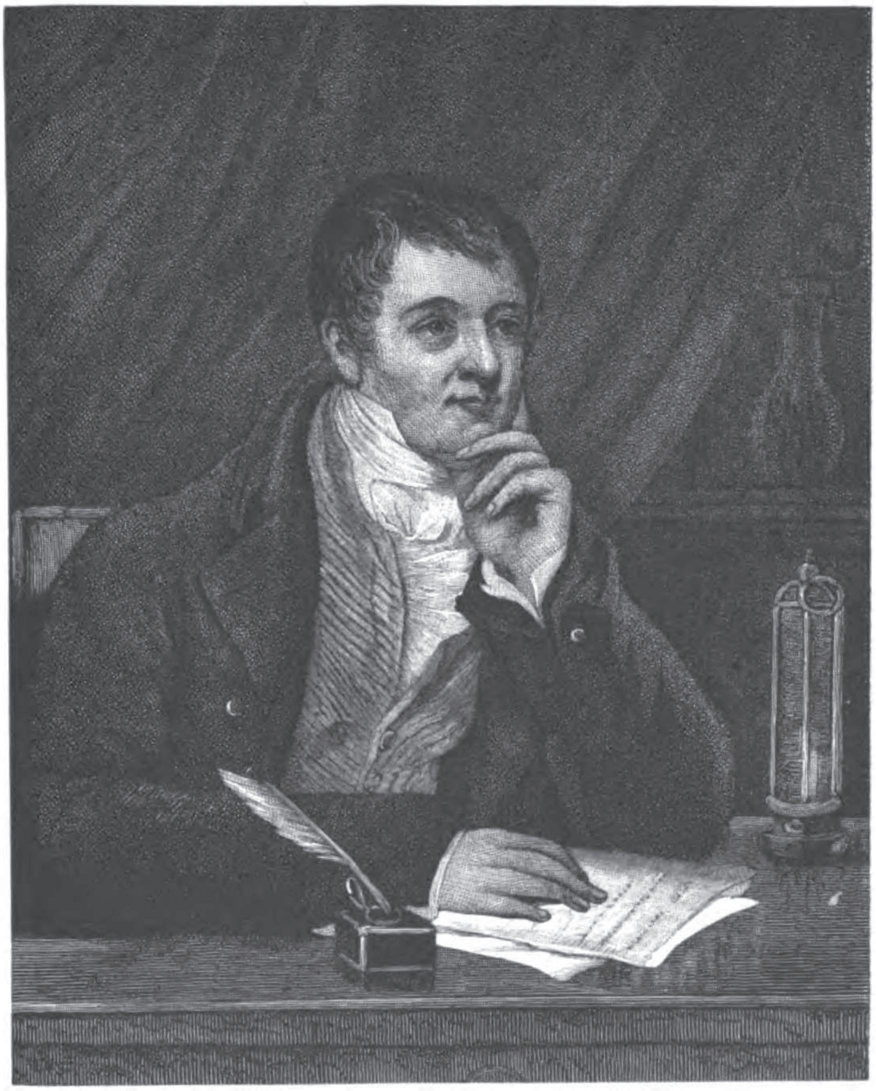
Volta, Inventor of the Voltaic Pile.

If the pith-ball electroscope be presented to one of the two rubbed bodies just mentioned, say the glass, it will be attracted to it, and after remaining in contact with it for a short time it will be repelled. If, now, it be presented to the other body it will be attracted. The two forces being oppositely directed in the two cases, as respects the charged bodies, we have a sufficient justification for saying that there are two kinds or states of electrification, and it is sometimes said that there are two kinds of electricity. The latter statement, however, must be understood to be only a convenient mode of expression which does not imply suspending one of the charged bodies so that it can move freely, and then presenting the other. An electric charge may be communicated to bodies which have not been rubbed, on merely bringing them in contact with one which is already electrified. For example, a light ball of pith suspended by a silken thread will be charged by such contact, and it can then serve as an electroscope; that is, it can be employed as a means of detecting the electric condition of any body to which it may be presented.* A light straw, balanced so as to turn freely on a fine point, may serve the same purpose.



OTTO GERICKE Patricius et Reipubl: Magdeburgensis Consul, ejusdemq; ad Univers Pac. Tract Monasterij et Osnabrugi Legatus. P. Aubry excud.

* Gericke was the first to observe repulsion between electrified bodies, and the inventor of the first electrical machine, about 1660.



any knowledge of the nature of electricity itself.

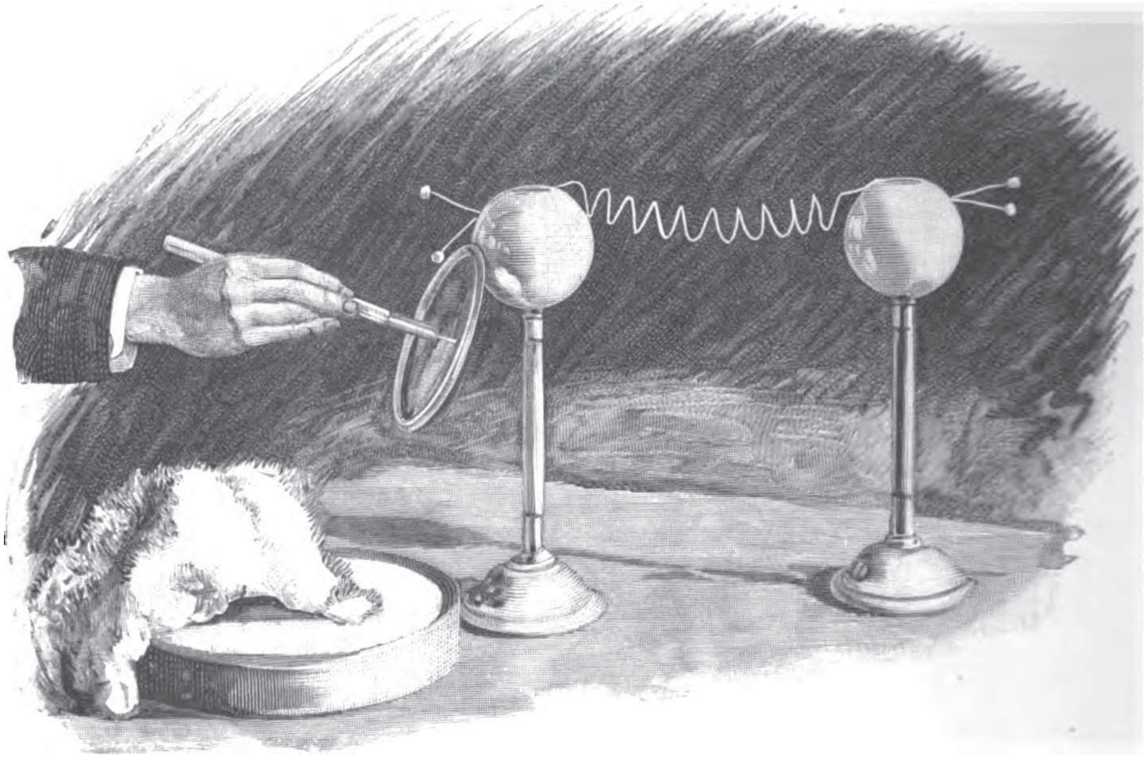
Electricians have adopted the language of mathematics, and they accordingly speak of one state of electrification as *positive* and of the other as *negative*, making the convention that the electrification, or the charge, which glass presents when rubbed with silk shall be regarded as positive.

When metals, and moist bodies which are not metallic, are held in the hand and rubbed, they do not show any signs of electrification. Such bodies, however, may be electrified by rubbing, if the precaution be taken to support them by means of glass, resin, or, in short, by any body which can be electrified by friction while held in the hand. A metallic sphere, for example, supported by a glass rod, may be strongly charged by

* Sir Humphry Davy was one of the earliest and most successful investigators of the effects of the electric current.

whipping it smartly with a piece of dry flannel.

Suppose two metallic spheres so supported, and joined by means of a metallic wire, as below, while somewhat remote from each other. If one of them be struck a few times with dry flannel, both charged in the same sense as the originally charged body. [P. 643.] This action of the one body on the other is called *induction*. If while this action is manifest the two spheres be widely separated from each other, the sphere which was originally charged will retain its



Insulated Metallic Spheres, electrified by contact with charged conductor and by conduction.

spheres will be found charged in the same sense. If, now, either of the spheres or the wire which joins them be touched with the finger, the entire electrification of the system disappears. The wire in this case is said to conduct electricity from one sphere to the other, or when touched, it, together with the person of the experimenter, conducts the electricity to the earth. All bodies which can act in this way are called *conductors*. Threads of silk, rods of glass, sealing-wax, and the like cannot act in this way, and accordingly they are called non-conductors or *insulators*.

There remains to be described another way of producing the charged condition of insulated conductors. If one of two insulated metallic spheres be charged by means of friction, and then be brought near the other, the latter will show signs of both electrifications at the same time—the remoter portion being charge, but the other will not. If the spheres be brought near together again, induction will take place as before. If, when this is done, the sphere which is subject to inductive action be touched with the finger, it will appear to be entirely discharged. On removing it from the influence of the inducing sphere, however, it will be found to be charged in the opposite sense. In this way it may be charged as many times as we please, and the successive charges may be employed for any purpose to which we may wish to apply them. We can thus produce an unlimited amount of electricity without impairing the charge of the inducing sphere. This can only be done, however, by the expenditure of work.

When two bodies are in different electrical conditions, so that an attraction exists between them, they are said to be at different *potentials*, or what is the same thing, there is said to be a difference of

Sir William Thomson's. After the plan of Harris.
Electrometers for Measuring Difference of Potential.

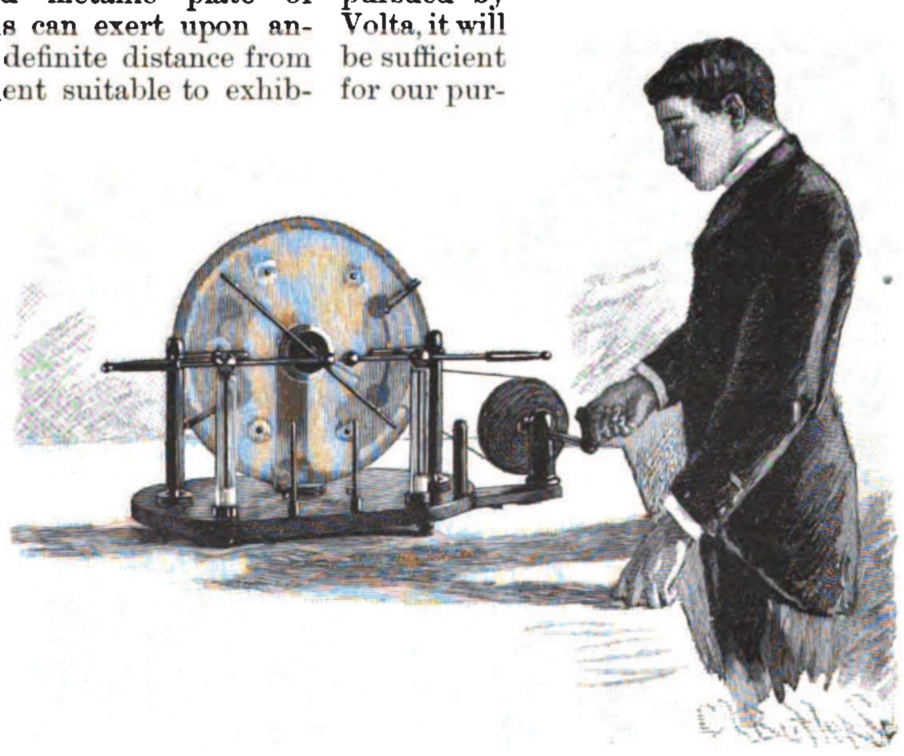
Electrical machines are only more or less convenient contrivances for producing great differences of electrical potential by means of friction or inductive action as above. [See Toepler-Holtz Machine, below.]

The laws of electrical attraction and repulsion thus far considered may be briefly stated thus: Unlike electricities mutually attract, and like electricities mutually repel. The attractions or repulsions are proportional, directly, to the product of the numbers which denote the quantities of the electricities concerned, and inversely to the square of the number of units which measure the distance between them.

potential between them. If the bodies are conductors, and if they be brought in contact, either directly or mediately, by means of a third conductor, a redistribution of electricity will take place, and they will then be at the same potential.

Difference of potential may be determined by weighing the attraction which a charged metallic plate of known dimensions can exert upon another plate at a definite distance from it. An arrangement suitable to exhibit the method is shown at the right in the illustration above. At the left is shown an electrometer, designed to accomplish the same end more conveniently and accurately. The attracting plates are in the interior of the apparatus, and the force is measured indirectly by means of suitable springs.

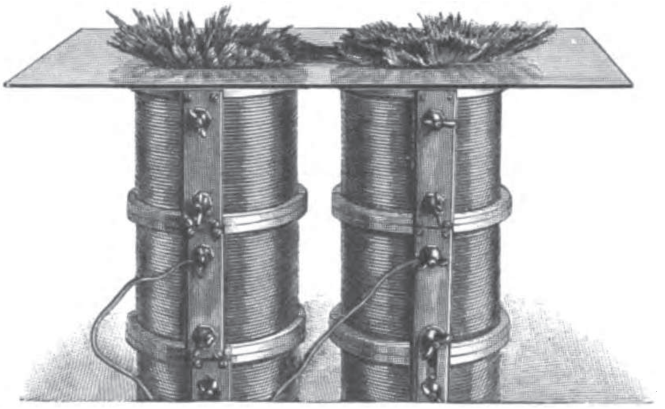
At the very beginning of the present century, Volta, stimulated by Galvani's recent discovery of what he called "animal electricity," invented the "pile" and the "crown of cups." We now speak of any equivalent arrangement as a voltaic battery. Without attempting to trace out the path of discovery and invention pursued by Volta, it will be sufficient for our pur-



Toepler-Holtz Electrical Machine.

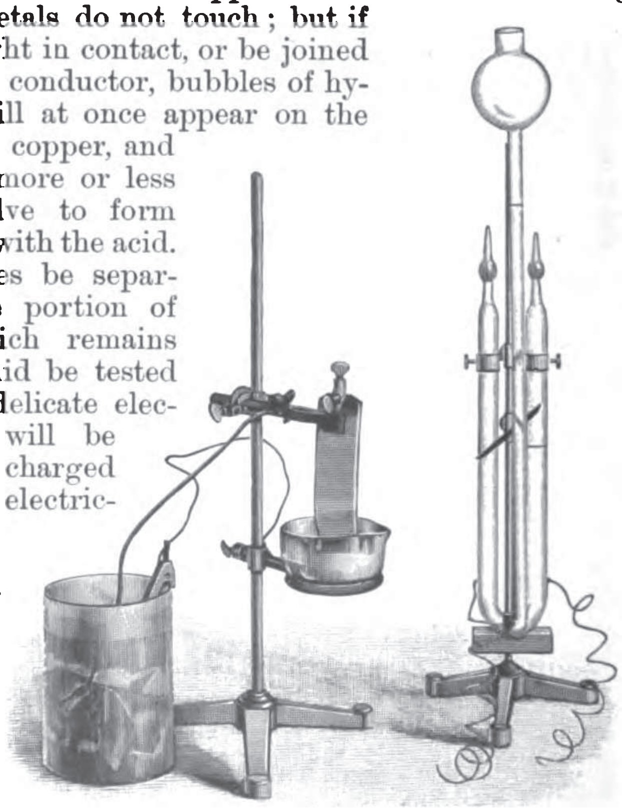
pose if we make clear the general construction and action of such an apparatus.

If a plate of zinc and a similar one of



The Magnetic Field, as indicated by iron filings thrown upon a pane of glass resting upon the poles of an electro-magnet.

copper be nearly immersed in water containing a little sulphuric acid, which may be held in any suitable vessel, no noteworthy action will be apparent so long as the metals do not touch; but if they be brought in contact, or be joined by means of a conductor, bubbles of hydrogen gas will at once appear on the surface of the copper, and the zinc will more or less rapidly dissolve to form zinc sulphate with the acid.



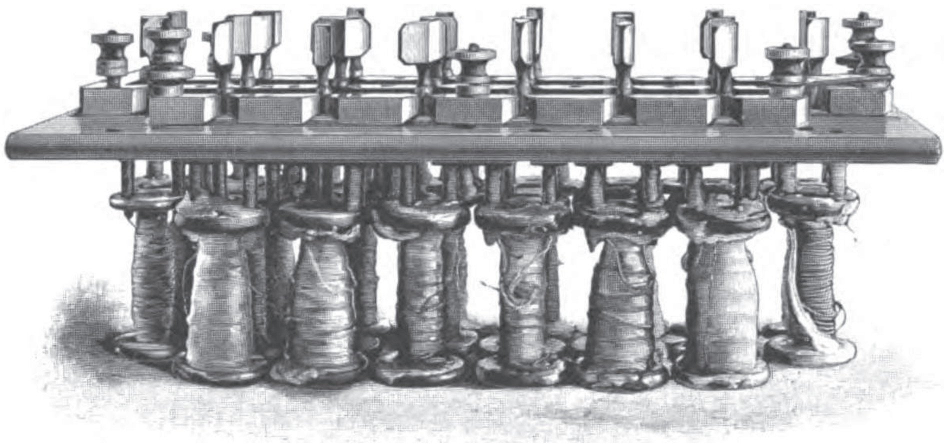
a. b. c.

Two Forms of Electrolytic Apparatus.

a, Battery; b, silver electrolyte in vessel; c, apparatus for electrolysis of water.

If the plates be separated, and the portion of the zinc which remains above the liquid be tested with a very delicate electroscope, it will be found to be charged with negative electricity, and in like manner the corresponding portion of the copper plate will be found to be charged with positive electricity. These charges are very feeble when compared with those which we can produce by even slightly rubbing a glass rod with a piece of silk. Volta, however, showed that in order to make these charges more evident we have only to combine the actions of several such arrangements as we have just described, by joining the zinc in the first vessel with the copper in the second, and the zinc in the second with the copper in the third, and so on. In this way the charges on the terminal plates, or *electrodes*, as they are called, may be increased to any extent. The difference of potential between the electrodes is ascribed to the action of a so-called *electromotive force*, arising from the interactions of the different substances employed in the construction of the battery, and having its analogy in the pressure which causes liquids to flow along through pipes. If a conducting wire join the electrodes or terminal plates of metal, a *current of electricity* will flow through it and through the battery, that is, through the metals and the liquids, which with the wire constitute a closed circuit. The *intensity* or strength of the current will depend on the magnitude of the acting electromotive force, and on the *resistance* offered to it by the entire circuit; and investigation shows that it is directly proportional to the former and inversely proportional to the latter. This relation is known as Ohm's law. It is of fundamental importance in both science and engineering.

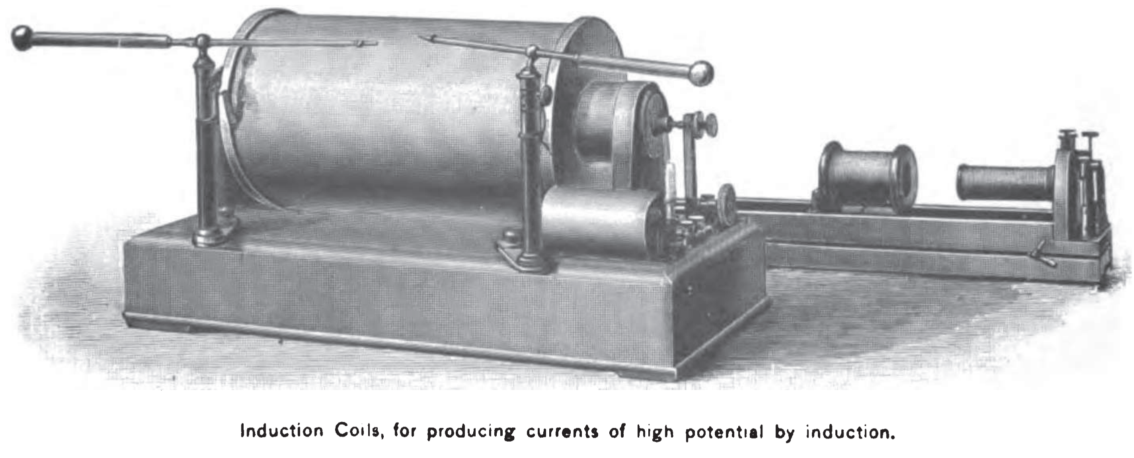
When a voltaic battery, such as we have described, is put in action by closing its circuit, the intensity of the current rapidly falls off. This is due to the fact that a counter electromotive force is set up by the hydrogen liberated on the copper plates, which reduces the electromotive force at first acting. This defect, which is common to other forms of voltaic batteries, may be more or less perfectly obviated in various ways. Motion may be given to the plates, whereby the gas will be detached; the plates may be made rough, so as to prevent the strong adhesion of the gas; but it is better to employ some exciting liquid which will not liberate any gaseous product in its action, such as copper sulphate, in the composition of which copper takes the place of hydrogen in the sulphuric acid. In case this salt of copper is employed, it is easy to so arrange the battery that the copper plate shall constantly receive a deposit of bright metallic copper, and so be kept free from adverse action. In the well-known Grove's form of voltaic battery the copper is replaced by platinum, a metal on which the strongest acids do not act, which is placed in a cup of unglazed porcelain containing strong nitric acid. This cup, with its contents, stands in the vessel which contains the zinc plate and the dilute sulphuric acid. The nitric acid is employed to supply oxygen which can unite with the hydrogen as rapidly as it is set free, and thus the platinum plate is kept in the most favorable condition, and counter electromotive force is avoided.



Resistance Coils, removed from box; showing their connections by means of plugs between metallic blocks.

If we wish to study some of the effects which may be produced by means of the battery current, we may employ with advantage a battery of ten or twelve Gróve's cups joined in series, that is, the zinc of the first cup joined to the platinum of the second, and so on. A conducting wire should be joined to the platinum of the first cup, and another to the zinc of the last cup.

If the two wires be brought in contact and then separated, a small bright spark will be seen when the contact is broken. The brilliancy of the spark will be much increased if the wires are wrapped around small pencils of hard carbon, and then



Induction Coils, for producing currents of high potential by induction.

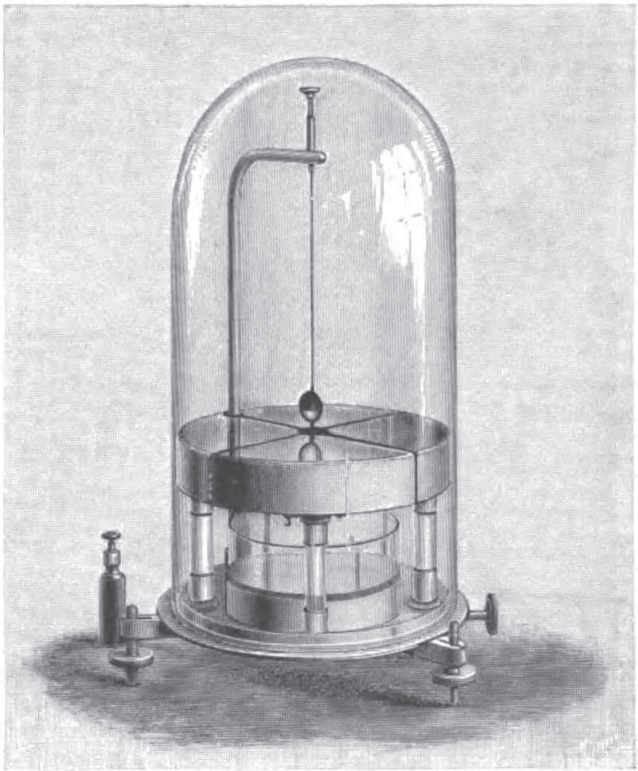
the latter brought in contact and afterward separated. If the difference of potential between the wires be increased by the employment of a series of cups amounting to forty or fifty, the current will continue to flow even when the pencils of carbon are separated to a distance of two or three millimetres. The carbon pencils will then be heated to an intense whiteness, and a light of dazzling brilliancy will be produced. This is the well-known *arc light* so generally employed in public lighting. The expense and inconvenience attending the use of any form of battery, however, is so great that other means are generally resorted to to supply the electric current, as will presently appear.

Gauss and Weber, who proposed and employed the system of absolute measurements, early in the present century.

If the carbon pencils used for the production of light be replaced by strips of platinum, and if the latter be plunged into water containing about one-tenth its bulk of sulphuric acid, hydrogen will be abundantly liberated from the platinum connected with the zinc electrode of the battery, and oxygen, amounting very exactly to half the volume of the hydrogen, will be liberated from the platinum connected with the platinum electrode. Chemical solutions of the metals may, in like manner, be decomposed by the action of the current. If any conducting body replace the platinum strip connected with the zinc electrode, it may be covered with silver, gold, nickel, or other metal, by employing the proper solution of the metal instead of the acidulated water. This action of the current is called *electrolysis*, and it is largely employed in the arts in the operations of electro-plating, electro-metallurgy, etc., as well as in the laboratory in chemical analyses.

Faraday, in the course of a masterly investigation, proved that a given amount of electricity passing through the *electrolyte*, as the solution to be decomposed is called, always sets free a definite amount of its constituents. He also showed that when the current passes through several electrolytes arranged in series, the constituents liberated in any one of them will be proportional to the combining weights of the constituents, respectively.

Various forms of electrolytic apparatus are employed. Those represented in

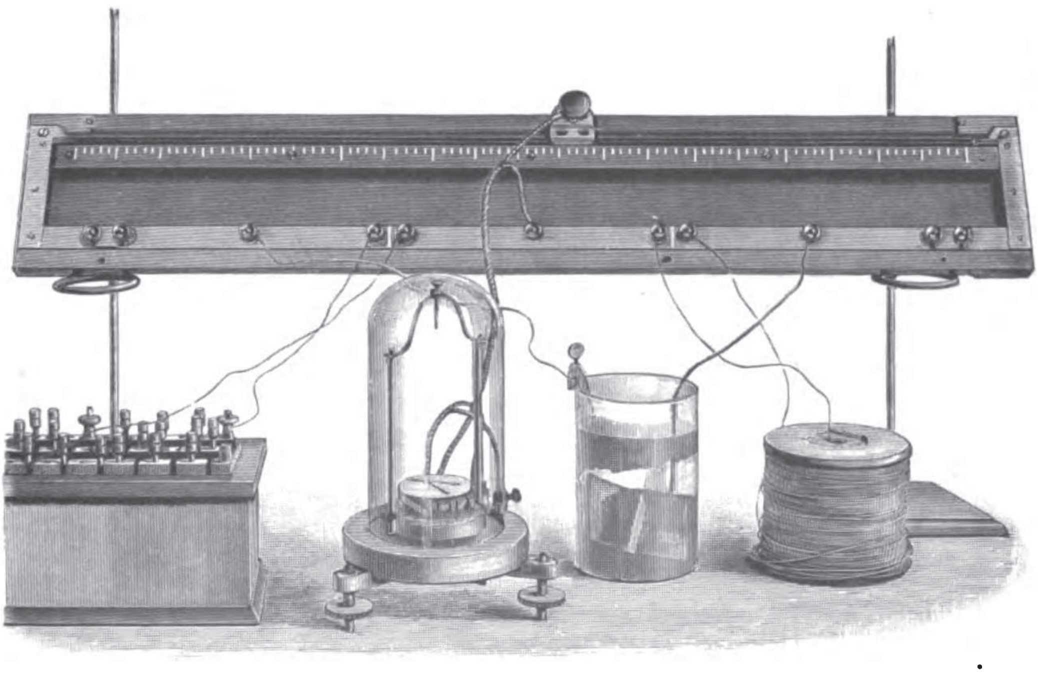


Thomson's Quadrant Electrometer, for comparing potentials.

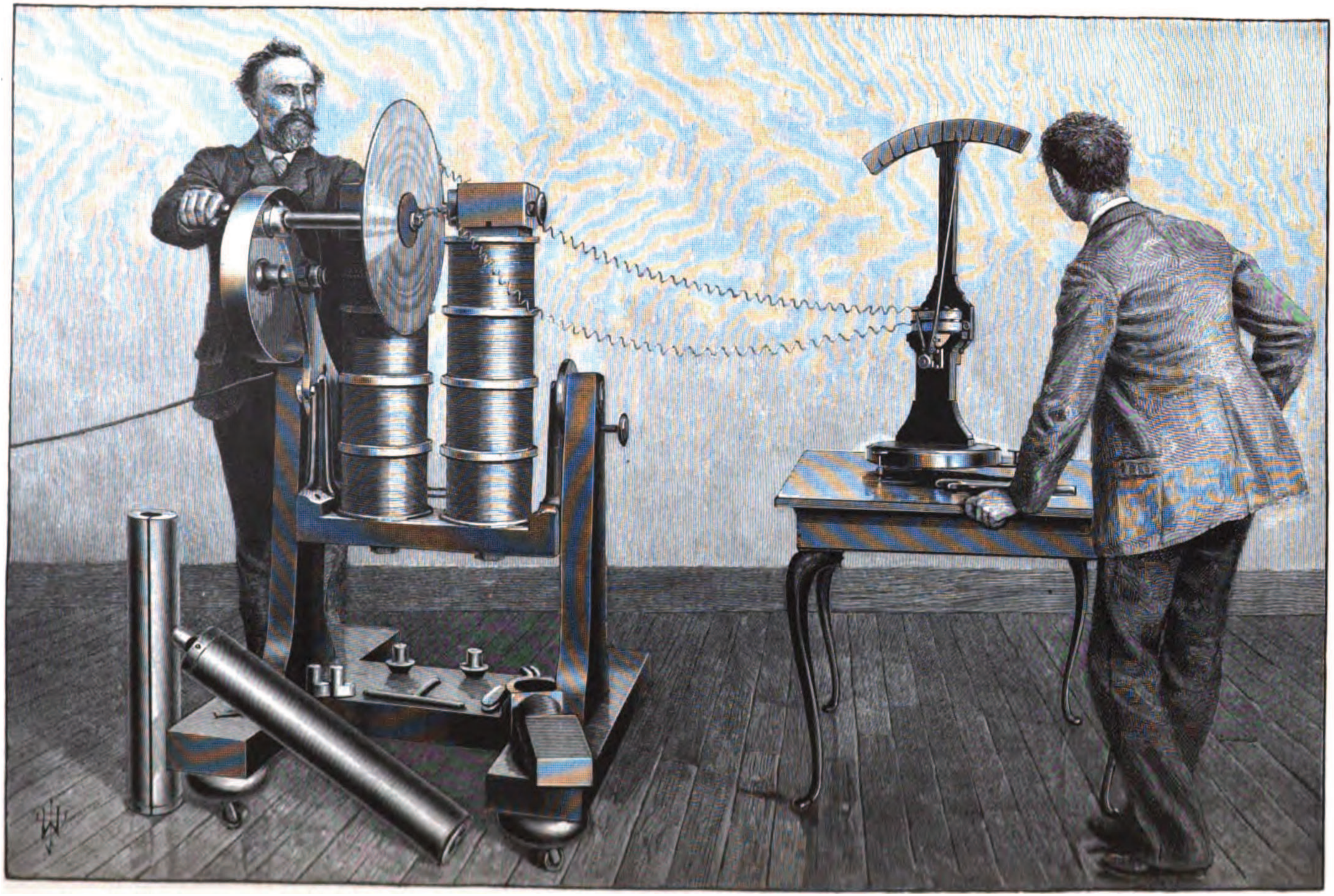
the illustration on page 648 are examples.

It will be seen that this law of Faraday gives us the means of comparing one current with another, or of comparing any current with a standard current defined in any way which may be chosen.

If, while the electrical current is flowing through a wire, a delicately poised magnetic needle be carried about it, the needle will tend to place itself at right angles to the general direction of the wire. It may be easily shown that the region about the wire is a magnetic region, commonly called a *magnetic field*. In order to do this, the wire may be made to pass vertically through a sheet of smooth paper which is held in a horizontal position. If, then, while the current is passing, some iron filings be sprinkled over the paper, and the latter be gently tapped, so as to assist the movement of the filings, they will arrange themselves in concentric circles about the wire. When the current is interrupted the region about the wire is no longer a magnetic field, but it may be restored as often as the current is renewed. This simple experimental fact lies at the foundation of many electrical appliances with which we are familiar. The magnetic field about a single conducting wire is, however, generally too feeble to serve for many purposes for which it would otherwise be useful.



Box of standard resistances. Galvanoscope. Battery. Conductor to be measured.
Above, sliding key for effecting balance.
Wheatstone's Balance, used for comparing resistances.



Current Produced by Conductor Revolving in the Field of a Powerful Electro-magnet.—Effect of current shown by galvanometer index displaced to right of scale.

In order to strengthen it we may increase the intensity of the current which flows through the conducting wire, or we may employ a sufficient number of conducting wires whose united actions will produce the desired result. The former plan is of limited application, since very intense currents involve great loss of energy in consequence of the heat which they develop, and if too intense it will destroy the conductor. In carrying out the latter plan it is easily seen that it is a matter of indifference whether one employ many separate conductors, each uniting the electrodes of an independent battery, or so dispose a single long conductor that it shall pass many times through the region which it is desired to convert into a magnetic field. The most economical and effective way of proceeding, therefore, is to coil the conductor into a compact helix or spiral. In order that the current shall traverse the entire length of the wire composing the helix, it is covered with an insulating material such as cotton or silk thread. If an open space be left in the centre of the helix, this space, as might be expected, is found, while a current is flowing, to be a powerful magnetic field. If, now, an iron rod be placed in the helix, it is at once powerfully magnetized. Such an apparatus is the well-known electro-magnet which, under one form or another, plays an essential part in a great variety of devices, including the telegraph, the telephone, the burglar-alarm, the dynamo-machine, etc.

Having now a clear idea of some of the more remarkable effects which may be produced by means of the electrical current, we may with advantage consider some additional means of producing the current itself. We have just seen that a bar of iron, when placed within a helix through the wire of which a current of electricity is flowing, becomes a powerful magnet. Experiment shows, conversely, that if the extremities of the wire constituting the helix be disjoined from the battery and brought in contact with each other, and if then a powerful magnet be thrust back and forth in the helix a current of electricity will be set up which will continue to flow so long only as the motion of the magnet continues. If a bar magnet be carried, in the direction of its length, quite through the helix, the current which is induced in the helix by this motion will be reversed in direction when the mid-point of the magnet passes the mid-point of the length of the helix; and if the magnet be thrust only half-way through the helix and then withdrawn, the same result will be produced. It is plain, then, that we can set up an electromotive force in a conductor by merely moving a magnet with reference to the conductor, and that we can determine the direction in which the electromotive force shall act to produce its corresponding current of electricity by our choice of direction in which the movement shall be made. Moreover, it is quite a matter of indifference whether we move the magnet or the conductor, or both, so long as the two change their relation to one another, and experiment shows that the magnitude of the electromotive force, and consequently that of the electrical current, is also under our control. It depends upon the strength of the magnet, on the velocity and direction of its motion, and on the number of turns of wire in the helix.

We might easily devise a machine operated independently, such as the steam-engine, which would continuously thrust a magnet into a helix and withdraw it, by a reciprocating motion. We should then have a means of producing currents of electricity which would depend upon mechanical power for the energy which must be supplied. For certain purposes the alternating character of the currents so produced would be a matter of no importance. It is not difficult, however, to devise means by which such a machine can automatically change the relations of the conductors, in which the currents flow outside of the helix, so that they shall flow always in the same direction. Any form of such apparatus is properly called a *magneto-electric machine*. [P. 652.]

In practice, machines of this general character are usually so constructed as to substitute rotatory for reciprocating motion, for the obvious reason that such a motion is more easily maintained. In order to carry out this plan it is only necessary to place permanently within the helix a mass of soft iron, which can readily acquire and lose the magnetic state on the approach and recession of a magnet, and then make a magnet rotate so that its poles shall pass rapidly in succession near the mass of iron, or, since it is equally efficient, make the helix, together with its iron core, rotate so that it shall be carried rapidly through the field due to the magnet. In either case the iron core, rapidly acquiring and losing its magnetism, will act precisely as if it were a permanent magnet having a reciprocating motion within the helix.

Obviously the permanent magnet in the apparatus just considered may be replaced by an electro-magnet, and better results may be secured, since such magnets can easily be made of far greater strength than the best permanent magnets possess. The electro-magnet so employed may, of course, be excited by the current supplied by a voltaic battery, but this inconvenience may be avoided by the simple device of sending the current produced by the motion of the helix through the coils of the electro-magnet, on whose presence the current itself depends. When this arrangement is adopted the current which is at first produced on setting the apparatus in operation is extremely small, since the electro-magnet is not then excited to action, and the feeble magnetic field which it presents is wholly due to accidental causes. When, however, the least current is produced by the motion of the helix, it is made to pass through the coils of the electro-magnet, which has its magnetism developed thereby, and thus presents a more intense field, and this in turn reacts to increase the current.

Such are the general principles involved in the construction and operation of the *dynamo-machine*. We need only add that in practice there are several movable coils symmetrically disposed about an axis, and constituting the *armature*. It will thus happen that one or more of the coils will always be passing through the most intense portions of the magnetic field. The current which is generated when the armature revolves is led away to be utilized by means of conducting wires joined to *brushes* or contact-devices, which are suitably held in contact with opposite sides of the revolving armature.

In the dynamo-machine we have an economical means of producing the electric current, since the mechanical energy which must be supplied to it costs less than an equivalent amount of available energy in any other form, and since there is no material contact of the working parts of the machine to wear them out.

The brushes which are applied to the armature are maintained at different potentials when the machine is in action. They may therefore be compared to the terminals of the voltaic battery; and, in short, it may be remarked that the relations expressed in Ohm's law hold good for the dynamo-machine and its circuit as well as for the battery.

If the current generated by a dynamo-machine be made to traverse the circuit of another and similar one, the latter will be set in rotation, and it will thus be a means of translating electrical energy into mechanical energy; in other words, it will become an *electric motor*, and may be employed as any other prime motor would be. Since the conductors which unite the machines may be as long as we please, we have thus a means of transferring power from one point to another. Obviously, however, we cannot do this in defiance of the law of conservation of energy, and as there will always be some energy expended in heating the conductors, we can never develop at the distant station as much energy as we expend at the transmitting one.

It is frequently desirable to exchange one current for another of different electromotive force and intensity. The inductive action of the current, through the magnetic field which accompanies its conductor, on other conductors in its neighborhood, affords the means of accomplishing this end. The apparatus by means of which the result is secured is called the *inductorium* or *transformer*. The special arrangement which is employed in any given case depends on the object to be accomplished. The most common form for use in the physical laboratory is shown in the illustration. [P. 649.] It consists of two helices of insulated wire of such dimensions that one can be placed within the other. The interior helix has comparatively few turns of thick wire and incloses a bundle of soft iron rods. The exterior one often has many thousand turns of thin wire.

When any change in the strength of the current which is made to pass through the interior helix occurs, a corresponding change takes place in the intensity of the magnetic field dependent upon it, and this, of course, produces a current in the exterior helix. The electromotive force of this current depends on the number of turns of wire in the helix. We can therefore secure as high electromotive force as we please by adding to the number of turns in the external helix. But every additional turn adds to the resistance and so diminishes the strength of the induced current. If we have given a current of high potential we may send it through the exterior coil and with every change in its strength we can secure a corresponding current of greater strength but of lower electromotive force.

In practice the current which is to be transformed is rapidly reversed or broken and renewed.

Since, as we have seen, an electric current may be employed to effect chemical decompositions, and since the constituents of an electrolyte so treated may set up a counter-electromotive force, it is clear that we may employ the current produced by the dynamo-machine to set free the constituents of chemical compounds which, on the withdrawal of the decomposing current, will reunite, and in so doing produce a current in the reverse sense. Such an apparatus is called a *storage*-battery. Thus, if two plates of lead which are covered with lead oxide be suspended, without touching, in a vessel containing dilute sulphuric acid, and if, then, a current from the dynamo-machine be passed through the plates and through the liquid, the plate connected with the negative electrode of the machine will give up its oxygen to the liquid, while the plate connected with the positive electrode will receive from the liquid an equal amount, in addition to that which it possessed at first. On disconnecting the electrolytic apparatus it may itself be employed as a voltaic battery. When conducting-wires from the lead plates are joined, a current is set up which continues to flow until the plates recover the condition which they had before the action of the dynamo-current. Evidently this electrolytic process of *charging* the storage-battery may be repeated as frequently as occasion may demand, the battery being in the meantime used for any purpose to which it is suited.

It remains now to consider, in the most general way, the scheme which electricians have adopted for the measurement of electrical quantities.

Since we know nothing of the ultimate nature of electricity, but must admit that it is as much a matter of conjecture as that of gravitation, it is clear that we can only base our measurements upon the effects which it can produce, just as we are obliged to do when dealing with the latter agency. Accordingly, we are quite at liberty to express our results in terms of the same *fundamental units* as are employed in physical measurements in general, and if we do so we shall obviously be able more easily to detect any relations which may exist between electrical and other physical phenomena.

It may be of service to the reader to define the fundamental units usually employed, and to point out how these enter into the derived units which must be employed in measuring complex quantities, such as velocity, acceleration, force, energy, etc. When once the method of procedure in measuring these quantities is clearly apprehended, there will be no difficulty in seeing how we are to apply it when we have to measure other related quantities.

Only three fundamental units are needed, and those usually selected are the unit of *mass* or quantity of matter, the unit of *time*, and the unit of *length*. The unit of mass is the *gram*; it is the one one-thousandth part of a standard piece of platinum called the kilogram. Masses are compared with copies of this unit of mass by means of the balance. The unit of length is the *centimetre* [0.394 inch], or the one one-hundredth part of the standard metre. The unit of time is the *second*, or the one eighty-six-thousand-four-hundredth part of a mean solar day. As the simplest example of a derived unit, may be mentioned that of a surface, or a square centimetre. It evidently implies extension in two directions, and into our conception of these extensions the notion of a length enters. We might, however, adopt an arbitrary standard of surface as our unit, and when we have occasion to measure a given surface we might find by actual trial how many times this standard unit can be applied to the surface so as to completely cover every part of it and no more. We should thus measure the given surface, but such a measurement would not be primarily based on a unit of length, and thus we should lose sight of important relations. In like manner we might adopt arbitrary units of velocity, acceleration, etc., but great difficulties would be involved as well as obvious disadvantages.

The notion of velocity implies both a time and a length, and a body moving uniformly in a straight line is said to possess *unit velocity* when it moves over one unit length—one centimetre—in one second. If a particle move in a straight line and change its velocity by one unit of velocity in one second, it has one unit *acceleration*. If the particle have a unit of mass, and be subject to unit acceleration, it is acted on by one *unit of force*. Change in the motion of a given mass is thus made the measure of force, and it will be observed that this does not raise any question as to the nature of force itself. The unit of force as just defined is called the *dyne*. It is obvious that a force may be applied to a body which is not free to move by reason of other forces which are acting upon it at the same time. In such cases we have recourse to some indirect method of determining what amount of motion would occur if the body were free to move.

If a body, by reason of its relations to other bodies, is able to exert a force of one dyne, through one centimetre of space, it has one *unit of energy*, called the *erg*. The energy of a body, or system of bodies, is defined as its ability to perform *work*. Since, then, energy and work are convertible quantities, it is clear that the erg is the proper unit of measure for work as well as for energy.

A familiar illustration of work is presented when a heavy body is raised from one level to another, as in building; and every reader is aware that in estimating such work both the amount of material raised and the height through which it is raised are taken into account. The work is numerically equal to the product of these two factors. This method of estimating work is sufficiently exact to meet the requirements of the contractor, but not sufficiently so for the purposes of science. The intensity of the earth's attraction is not the same at all points on its surface, and so it follows that the amount of work which must be done in order to raise equal masses through the same height is not everywhere the same. It is not difficult, however, to determine, by means of the pendulum, what acceleration a body falling freely will be subject to at any place. When this is known we can completely specify the force which acts on any given mass by taking the product of the number of units in the mass by the number of units of acceleration. For New York the acceleration due to gravity is about 980 centimetres per second, that is, a body starting from rest and falling freely will acquire a velocity of 980 centimetres in one second. If, therefore, we multiply the number of grams contained in a given body by 980 we have the value of the force acting on the body. This is called, in scientific language, the *weight* of the body.

Any region in which a mass is acted upon so as to produce, or tend to produce, an acceleration is called a field of gravitational force. In like manner, a region in which a magnet pole is acted upon so as to produce a similar result is called a field of magnetic force, and a region in which an electrified body is so acted upon is called a field of electric force. We must not infer, however, from these forms of expression, or from what we may imagine respecting the regions to which they are applied, that there are several kinds of force. The expressions are in no sense qualitative, but merely indicate the conditions under which a stress will arise such as will tend to produce an acceleration in a body.

Now, the earth itself may be regarded as a great magnet, since it acts on magnets just as they act on each other. The earth is accordingly accompanied by a magnetic field, of which the intensity varies at different points, though not according to any established law. The intensity, however, of the earth's magnetic field at any place can be ascertained by a method in general similar to that employed in determining the intensity of gravitation.

The ratio of the intensities of the two magnetic fields, the one due to the earth, and the other to the action of the current, is determined by the position which a needle, hung free from restraint, assumes under their joint action. But the intensity of the field due to the current depends on its strength, on the distance of the needle from the conductor, and on the number of times the conductor passes through the region. If, then, the conductor be coiled so as to form the circumference of a circle, and have its ends accessible so as to be connected with the source of the current, and if a short magnetic needle be so suspended that its centre of form shall coincide with the centre of the coil, we have all that is essential to a *galvanometer*. Of course, such an instrument would be furnished with a divided circle, or similar device, for convenience in determining the position of the needle when under the influence of the current to be measured. It may easily be shown that the intensities of any two currents are to each other as the tangents of the angles of deflection from the magnetic meridian which they respectively cause the needle to make. Hence the instrument is called a *tangent galvanometer*.

By the aid of the tangent galvanometer and the foregoing principles we can do more than to compare one current with another in terms of the tangents of the angles of deflection which they can cause—we can determine the value of any given current in terms of our fundamental units, or in *absolute measure*, as it is called. In order to this we define the unit magnet pole and the unit current in accordance with the conventions already made when dealing with velocity, acceleration, etc.

A unit magnet pole is one which exerts a unit force upon a similar and equal pole at unit distance.

The unit current of electricity, for every centimetre of its length, can exert a unit force upon a unit magnet pole at one unit distance from every portion of the current. The only disposition of the conductor conveying the current which will meet the last condition is that of a circular coil with the needle at its centre. This disposition is found in the galvanometer described above. As the radius of the coil described in the definition of unit current would be too small for practice, we have only to employ coils of any convenient, but known, radius, and make the necessary computations, remembering that the effect of the current is inversely as the square of its distance from the magnet pole.

It will be noticed that our definition of current involves but a single magnet pole, whereas the galvanometer of necessity has a magnetic needle of two poles, since one pole cannot exist without another having exactly opposite properties; and, further, nothing is assumed to be known, in the description of the galvanometer, about the strength of the poles of the needle employed. These circumstances, however, cause no inconvenience, since the only use we make of the needle is to ascertain the ratio of the intensity of the horizontal component * of the earth's magnetic field to the intensity of the field due to the galvanometer coils through which the current to be measured is passing. But the intensity of the horizontal component of the earth's field is known as above, in absolute measure, or, in other words, we know the velocity which it would impart to a free magnet pole weighing one gram. The intensity of the field due to the current, and therefore the intensity of the current itself, is then easily found. Thus it is seen that the intensity of the current is measured in the same fundamental units as are employed in measuring the stress between a heavy body under the action of gravitation. The real standard of comparison is the horizontal component of the earth's magnetism. The number representing this, in the neighborhood of Princeton, is about 0.18 centimetre—in other words, the

* The direction of the earth's magnetic force is oblique to the horizon. By "horizontal component" is meant the amount of force which it can exert horizontally.

velocity along the magnetic meridian which a free magnet pole weighing one gram would acquire in one second is about 0.18 centimetre. The corresponding velocity which any body would acquire under the action of gravitation is about nine hundred and eighty centimetres, or about five thousand four hundred and forty-four times greater.

The unit of current, as defined, would necessitate the employment of inconveniently large numbers in calculations involving the related quantities, electromotive force and resistance. To avoid this another unit, called the *ampère*, is used in practice. It is one-tenth the *electro-magnetic* unit, as the unit of definition is called.

In order to present an idea of the unit of electromotive force, we may imagine an experiment of very simple character, although its execution would be very difficult. Let a long straight conductor be bent upon itself at its middle point, so that the two straight portions shall be at all other points at unit distance from each other, and let the conductor thus formed be so fixed in a magnetic field of unit intensity that the plane in which the conductor lies shall be at right angles to the direction in which a magnetic needle points; if, now, a second conductor slide along in contact with both branches of the fixed conductor, so that all positions successively assumed shall be parallel, and with unit velocity there will be unit electromotive force set up in the circuit. An equivalent experiment has been carried out in which a coil of wire of known dimensions was made to revolve with a known velocity in the earth's magnetic field. From the data thus at hand the electromotive force was calculated. It is evidently in terms of the known intensity of the earth's magnetism at the place of the experiment and of velocity.

Since there is an electromotive force set up in the revolving coil, there will be a current in it which may be measured by making suitable connections of its terminals with the galvanometer. Both the current and the electromotive force being thus known, the resistance of the entire circuit is readily found by Ohm's law. It is simply the ratio of the electromotive force to the current.

The electro-magnetic units of electromotive force and resistance defined as above are too small for practical use. The *practical* unit of electromotive force is therefore taken 100,000,000 times greater, and is called the *Volt*. The unit of resistance is taken 1,000,000,000 times greater, and is called the *Ohm*.

If the wire of which the revolving coil and the galvanometer coil are formed is of uniform character and diameter, and if we find their joint resistance, we can easily prepare proportionate lengths of similar wire which will represent one ohm or any given number of ohms. Sets of such wires, coiled and so mounted upon an insulating support that they may be joined in any way desired, constitute what are called *resistance coils*. [P. 649.] They are concrete standards of resistance, and in theory they are used just as standards of length, mass, etc., are used.

One of the most obvious methods of comparing the unknown resistance of any given conductor with that of a standard coil will be understood by considering the effect of friction on the flow of water in pipes. If a pipe be selected as a standard, through which, with a given constant pressure of water, exactly one gallon will flow in one second, it is evident that any other pipe which, under the same conditions, will deliver the same amount must offer the same resistance. If the pipe under trial deliver only one-tenth of a gallon, it evidently offers ten times the resistance of the standard. In the case of electrical conductors we may maintain the electromotive force constant, and determine the number of ampères which flow through the standard resistance wire, and that whose resistance is to be measured successively. Their resistances will be inversely as the number of ampères which can respectively pass through them. This would be an inconvenient method in practice, and accordingly others have been devised, but our limits forbid presenting them. [See *Wheatstone's balance* on page 651.]

The energy expended by a current in passing from one point to another of the conductor is due to its loss of potential. The equivalent work may appear in heating the conductor, as in electric lighting, in electrolytic work, or in mechanical work according to the devices included in the circuit.

The power, or, in other words, the rate at which work is done when one ampère of current suffers a loss of potential equal to one volt is called a Watt. It is 10,000,000 ergs per second, or about one seven-hundred-and-forty-sixth part of a horse-power.

An example will illustrate the use which may be made of these relations. It requires about ten ampères of current to operate an arc-lamp such as is employed in street-lighting. The current suffers a loss of about fifty volts at each lamp. If there be fifty lamps in the series the entire loss will be 2,500 volts. This number, multiplied by 10 and divided by 746, gives between thirty-three and thirty-four horse-power, which will be required to operate all the lamps.

In conclusion, it may be worth while to emphasize what has already, perhaps, sufficiently appeared, namely, that we can entertain no expectation that electricity of itself will ever in our hands become a *source* of energy with which we can operate factories, drive trains, etc. It can only play a part in our service when there is a difference of potential between the points of its application, and, in order to secure this difference of potential, work must be done, in general, greater in amount than can be recovered from the fall of potential when equilibrium is restored. Similar disadvantages attend the use of other means of applying energy, such as belting, shafting, steam and water in pipes, etc.

It would be quite impossible to forecast the future, even for a single decade, with reference to the applications of electricity, even though discovery were ended. The mere expansion of industries already in some degree established will give them an importance which we cannot now estimate. But discovery is not ended, and it is more than probable that results will yet be reached which, although they cannot be at variance with the general doctrine of energy as now understood, may, to some extent, revolutionize our methods, with corresponding advantages.

SAPPHO TO PHAON.

By Margaret Crosby.

Last night I dreamed you kissed me on the lips.
Instead of all the wild and sweet surprise
I feel if you but touch my finger-tips
In waking hours, I coldly met your eyes
And heeded not your fiery words that burn
Too late. . . . To-day you passed me with a glance—
I live—no! starve upon that look, and yearn
For all I spurned in sleep. O hard mischance
That night should heedlessly and without ruth
Tangle anew the daylight's waste and cheat!
Waking or dreaming—which, love, is the truth?
I may not know—yet this one thing were sweet:
That, ere forever vanishes our youth,
My waking self thy dreaming self might meet.