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ELEMENTS

OF

STATIC ELECTRICITY

WITH

FULL DESCRIPTION OF THE HOLTZ AND TÖPLER MACHINES
AND THEIR MODE OF OPERATING.

By PHILIP ATKINSON, A.M., Ph.D.

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INTRODUCTION.

IN this treatise the principles of electricity are presented untrammelled, as far as possible, by mathematical formulæ, so as to meet the requirements of a large class who have not the time or opportunity to master the intricacies of formulæ, which are usually so perplexing to all but expert mathematicians.

This class includes those whose knowledge of electricity is limited to the practical details of telegraphy, telephony, and electric lighting; also those among the liberally educated, who desire to review electric science in the light of recent investigation; and those who wish to study its elementary principles, preparatory to a more extended course, which shall embrace all the details of electric measurement and electric engineering.

The original plan included dynamic as well as static electricity, embracing its practical application to the arts; but it was subsequently thought best to confine the present work to static electricity alone, to meet the wants of those who are less familiar with its principles than with those of dynamic electricity, and to

reserve the consideration of the latter for a separate volume.

Care has been taken to avoid the introduction of new matter before the student was prepared for it; hence it was thought best that there should be a thorough examination of elementary principles before introducing complicated apparatus, the construction and operation of which depends on those principles.

The theory assumed is, that electricity is one of the forms in which energy manifests itself; that its nature is not changed by the means employed to generate it, and that the various terms, *positive*, *negative*, *static*, *dynamic*, express certain conditions and relations in which this manifestation occurs, and not different kinds of electricity.

The author takes pleasure in acknowledging his obligations to Elisha Gray for the use of tables, giving the results of observations on earth currents, made under his direction on the Postal Telegraph line; also to Ferguson, Gordon, Silvanus P. Thompson, Noad and Deschanel, from whose excellent works valuable assistance has been obtained, though he has felt compelled to dissent from some of their views.

The views here expressed are the result of many years' experience in the class room, the lecture room, and the laboratory, and were adopted only after the most rigid test of actual and oft repeated experiment. And some of the more important apparatus described

is of the author's own manufacture, constructed in strict accordance with electric principles, verified by his own experiments.

While humbly following the great pioneers in electric science, who have hewed waymarks on the rocks, the author will rest content if he has left some foot-prints on the sands, which may serve to guide the wayfarer till obliterated by the coming waves of progress.

The impartial criticism of teachers and electricians is especially requested, that faults and errors may be corrected in future editions.

PHILIP ATKINSON.

CHICAGO, June, 1886.

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ELEMENTS OF STATIC ELECTRICITY.

CHAPTER I.

ATTRACTION AND REPULSION—CONDUCTORS AND
NON-CONDUCTORS—QUANTITY AND INTENSITY—
STATIC ELECTRICITY DEFINED.

ATTRACTION AND REPULSION.—Amber, called in Greek *ηλεκτρον*, was known to the ancients to acquire, when rubbed, the power of attracting light bodies; hence this property, now known to belong to all substances, has received the name of electricity. The earliest conception of electricity, then, was that of force, and the latest discoveries sustain this view.

Electricity may be generated by various simple methods, as follows:—Let a spoon be balanced on the edge of a cup, and an ebonite (hard rubber) knife-handle, rubbed on a woolen or silk fabric, be held near it, and the spoon will be attracted. Substitute for the knife-handle a stick of sealing-wax, a lamp-chimney, or a paraffin wax-candle, rubbed in the same way, and the spoon will be attracted by each of them.

These different substances may be multiplied, and different rubbers used, but it will be found that the

attractive force, though variable in intensity, is common to all.

The *balanced rod*, represented in Fig. 1, will be found more convenient for these experiments than the balanced spoon. It consists of a round wooden rod, about twenty inches long, and half an inch in diameter, with the ends rounded or terminating in balls. It is pivoted at the center on a point, and may be mounted on a stand, or on a bottle with a pin through the cork, and made to revolve rapidly by the force of attraction, following any of the electrified bodies already mentioned when held near it, as represented.

Fig. 1—The Balanced Rod.

A more sensitive instrument for investigations of this class is represented in Fig. 2, and known as the *pith-ball electroscope*; the name electroscope being derived from the Greek *σκοπεω*, to see, *ηλεκτρον*, electricity. It is constructed as follows: A small brass rod, bent at right angles, has its short arm inserted into an ebonite stem attached to a wooden base, giving the instrument a vertical height of about $11\frac{1}{2}$ inches. The horizontal arm is about 8 inches long, and terminates in a small brass ball. From this arm two pith balls, each about half an inch in diameter, are suspended by silk threads.

Let the pith balls be separated at the points of suspension, so that when they hang vertically a considerable space shall intervene between them, and let a stick of sealing-wax, previously electrified by friction, be brought near one of them; the ball will be attracted to the wax, and, after a momentary contact, repelled. Follow it with the wax, and it continues to recede as if pushed back by some invisible barrier.

Now let the other pith ball be moved near this one, and they will be attracted to each other, and, after contact, repelled; the lines of suspension showing divergence in each direction as represented.

Let the electrified wax be again brought near, and each ball is repelled by it, so that when it is placed between them, they are driven further apart; but let any non-electrified body be brought near and they are attracted to it.

If each of the balls be separately electrified by the wax, and they are then brought near each other, they will show mutual repulsion without previous attraction.

From this series of phenomena we learn, first, that electrified bodies not only attract non-electrified bodies, as already shown, but communicate electricity to them by contact; and, secondly, that bodies electrified, either by each other or from the same source, show mutual repulsion.

Fig. 2—The Pith-Ball Electroscope.

The first fact was shown when the pith ball, after contact with the wax, attracted and electrified the other pith ball; and the second fact by the repulsion of the pith ball from the wax after contact; then of the two pith balls from each other and from the wax, after contact; and finally by the mutual repulsion of the balls, without previous attraction, after being separately electrified by the wax.

This series of phenomena may be produced by using a glass or ebonite rod, or any of the substances already mentioned, as well as by the sealing-wax; showing that repulsion as well as attraction is a property common to all electrified bodies.

CONDUCTORS AND NON-CONDUCTORS.—Pursuing our investigation, new properties are developed. It is found that while certain substances, as glass, ebonite, and sealing-wax, show electric qualities, others, as brass, iron, and copper, apparently do not show such qualities. This led to the old division of all substances into *electrics*, a term applied to the former, and *non-electrics*, applied to the latter.

But more thorough investigation has proved that electricity may be generated by friction on the brass, iron, and copper, as well as on the glass, ebonite, and sealing-wax; but that, when generated on bodies of the former class, it is instantly distributed over the entire body, and escapes to the earth unnoticed, if the body be held in the hand, while, when generated on bodies of the latter class, it is not so distributed, and does not pass off in this way; bodies of the former class allowing free electric movement, over the surface or through the mass, while those of the latter class resist such movement.

To make this evident, let a short brass rod, of about quarter inch diameter, terminating in a ball, be fitted to an ebonite handle, as represented by Fig. 3.

Fig. 3—The Insulated Metal Rod.

Let the brass be rubbed briskly on woolen, silk, or india rubber, holding the instrument by the handle, and it will attract and repel the pith balls in the same way as the other electrified substances already used. Copper, iron, or any other metal may be substituted for the brass with the same result.

Repeat the experiment, allowing the metal to touch the hand, and the electric qualities disappear. This shows that in the first experiment the electricity was retained, because it could not pass through the ebonite handle; while, in the second, it passed off through the hand.

The results obtained by experiments of this kind led to the abandonment of the doctrine of electrics and non-electrics, and the classification of all bodies as *conductors* or *non-conductors*.

Experiment proves that all substances conduct electricity, and that they all offer a certain amount of resistance to its passage. But it is found that the relative proportions of conductivity and resistance vary greatly in different substances. In some the conductivity is largely in excess, and they are called *conductors*; in others the resistance is largely in excess, and they are called *non-conductors*. Between these extremes there are all degrees of variation; so that in some substances the two properties are almost equally balanced. Hence, since no exact rules can be given, we distinguish the two classes by saying that a CONDUCTOR is any sub-

stance of such low resistance that it can be used practically for the transfer of electricity; and a NON-CONDUCTOR is any substance of such high resistance that it can be used practically to prevent such transfer.

LIST OF CONDUCTORS AND NON-CONDUCTORS.—The principal conductors are the metals, silver and copper being the best. Among the partial conductors are the different varieties of carbon, including coal, charcoal, and graphite; the acids, saline solutions, water, vegetables, and animals.

The principal non-conductors are caoutchouc, gutta-percha, sulphur, and their compound, known as hard rubber, vulcanite, or ebonite; dry air, paraffin, shellac, amber, resin, glass when free from metallic substances, mica, silk, fur, wool, hair, feathers, bisulphide of carbon, petroleum, and oil of turpentine.

Among the partial non-conductors are porcelain, baked wood, paper, and leather.

INSULATOR DEFINED.—When a non-conductor is used in connection with a conductor to confine electricity within certain limits, it is called an *insulator*; and the conductor on which the electricity is confined, or to be confined, is said to be *insulated*; as a metal placed on a glass or ebonite support, a copper wire wrapped with silk or wool.

QUANTITY AND INTENSITY.—Electric quantity and intensity are similar to the quantity and intensity found in other more familiar forms of energy. The intensity of any form of energy, other things being equal, is inversely proportional to the mass of the body in which it is developed. A few strokes of a hammer on a small piece of iron placed on an anvil will raise its temperature to a burning heat; while the same number of

strokes on a large mass of iron will produce but very slight change of temperature. The *quantity* of muscular energy expended is the same in each case, but the *intensity* of heat energy produced varies inversely as the mass.

The intensity varies also as the resistance. A small piece of wood held in the flame of a lamp is quickly ignited at the end in the flame; while the end held in the hand shows no perceptible change of temperature. But a brass rod of the same size, similarly held for the same length of time, becomes too hot for the hand long before the end in the flame is hot enough to ignite wood.

In the wood, the intensity rises rapidly at the end held in the flame, because the resistance prevents distribution of heat through the mass. But the low resistance of the brass permits the rapid distribution of the same quantity of heat through its mass; so that the intensity at the end in the flame is much less than that of the wood.

In kindling a fire of anthracite coal, when the proportion of coal is too great for the kindling-wood, the heat generated by the consumption of the wood fails to ignite the coal, because such coal being a comparatively good conductor of heat, the amount is rapidly distributed through the mass, and hence the intensity at any point is insufficient to produce ignition. But if the proportion of coal be sufficiently reduced, the consumption of the same amount of wood will produce ignition. The quantity of heat imparted to the coal is the same in each case, but its intensity is greater in the latter case.

In electric experiments there is a great difference noticeable in the amount of work required to produce

the same electric intensity on different bodies. Sealing-wax and ebonite, for instance, are quickly electrified, while brass is electrified slowly. The reason is analogous to that in the illustrations just given: the brass being a good electric conductor, the electricity is instantly distributed equally over every part of its surface, and hence the quantity at any point being small, the intensity is low. But the sealing-wax and ebonite being good non-conductors, the same quantity of electricity is concentrated on those parts of the surface brought into immediate contact with the rubber, instead of being equally distributed over the entire surface; and hence the intensity at those points is proportionately increased.

It will be shown hereafter that in static electricity the electrification is on the surface. Hence, in this case, *electric intensity means quantity in proportion to surface*, whether it be the entire surface, as on a conductor, or only those parts to which the electrification is confined, as on a non-conductor.

It must also be understood, as will be shown more fully hereafter, that the term intensity is as applicable to a diminution of electric energy at a given point as to an increase; in the same sense as we speak of intense cold, as well as of intense heat.

STATIC ELECTRICITY DEFINED.—The terms used to distinguish different classes of electric phenomena, as *frictional, static, galvanic, chemical, magneto, thermo*, take their origin from the different methods by which electricity is generated, and the various conditions under which its phenomena have been observed, and should not be understood as referring to any difference in the nature of the electricity produced.

The term *frictional* has been used to designate that class of phenomena now under consideration, since friction is one of the principal agencies by which the electricity is generated. But it seems more appropriate to use a term embracing, not merely one agency by which the electricity is generated, but also the various phenomena produced, and distinguishing these phenomena from those pertaining to electricity generated by other methods. And since these phenomena refer chiefly to electricity when stationary, the term *static*, from the Latin *sto*, to stand, has been adopted, to distinguish electricity observed under these conditions from electricity observed chiefly in a state of motion.

CHAPTER II.

ELECTRIC POTENTIAL.

POTENTIAL.—Potential, in the physical sense, is the power to accomplish work. It derives its specific name from the nature of the work, as *gravity* potential, *heat* potential, *electric* potential.

A pound weight raised to the height of ten feet has acquired ten foot-pounds of gravity potential, and has the power, if allowed to descend to the same level, of accomplishing ten foot-pounds of work, either in raising another weight, or setting machinery in motion by which work may be accomplished.

A mass of metal whose temperature has been raised from zero to one thousand degrees, has acquired one thousand degrees of heat potential, and can accomplish work to that amount in cooling to zero, either by heating another mass, or generating steam by which machinery can be put in motion and work accomplished.

We have seen that bodies, when electrified, acquire the power to attract or repel other bodies. This power is called electric potential.

Suppose that the electric energy of the sealing-wax in attracting the balanced rod, represented in Fig. 1, Chapter I., were just sufficient, if expended without loss, to move the rod one foot; and, in doing so, to overcome a resistance from inertia and friction represented by two ounces (one-eighth of a pound); the

electric potential of the sealing-wax would equal one-eighth of a foot-pound.

If only half this energy were required to overcome inertia and friction, the other half might be expended in lifting to a height of one foot an ounce weight attached to a thread fastened to the end of the rod, and passing over a pulley. In which case the work accomplished by this half would be represented by one-sixteenth of a foot-pound. Or the weight might be raised, or other work to the same amount accomplished, by putting in motion light machinery connected with the rod by gearing at its center; the added friction being included in the ounce representing friction and inertia.

Repulsion would evidently produce the same results in this case as attraction.

To distinguish between electricity and electric potential, we must bear in mind that electricity represents the energy itself, while potential represents certain relations between this energy and matter. Hence we derive the following definition:

Electric potential is the power which a body possesses to accomplish work by virtue of its electricity.

DIFFERENCE OF POTENTIAL.—To accomplish work in this way there must first be a difference of potential.

The descending weight could not raise the other weight unless there was a difference of level between them. The heated metal could not heat a similar mass unless there was a difference of temperature between them. Neither could the electrified sealing-wax attract the rod unless there was a difference of electric energy between them. And these phrases, difference of level, difference of temperature, difference of electric energy,

are simply different forms of expression for difference of potential.

To produce this difference work must first be expended, and this work is the measure of the potential acquired.

The lifting of the pound weight ten feet against the force of gravity gave it the ten foot-pounds of gravity potential. The work of heating the metal, whether represented by combustion, by friction, or by concussion, gave it the one thousand degrees of heat potential. And the rubbing of the sealing-wax gave it the one-sixteenth of a foot-pound of electric potential.

As there is ordinarily no practical difference of electric potential between different points on the earth, within a limited area, its potential is considered zero, and taken as the base of all measurements of electric potential.

The qualification of this statement, as above, becomes necessary, since there are often great differences of potential over widely separated areas.

POSITIVE AND NEGATIVE.—Bodies whose potential is higher than that of the earth are said to have *positive* potential, while those whose potential is lower are said to have *negative*.

The potential of bodies is also considered positive or negative with reference to each other. If a body has a higher potential than the earth, but lower than that of another body, it is said to be positive with reference to the earth, but negative with reference to the other body. In like manner a body may have negative potential with reference to the earth, but positive with reference to another body of lower potential.

Hence, *positive and negative are merely convenient rela-*

tive terms to designate different degrees of potential and not different kinds of electricity.

The sign (+) is used to denote positive potential, and (—) to denote negative potential.

The earth's potential, then, is the electric zero, just as the freezing point is the zero of temperature in the centigrade thermometer, and all *uninsulated* bodies are said to be *connected with the earth*, and to have zero potential when not under special influence from insulated, electrified bodies in their vicinity.

When the electric potential of a body is changed from zero by an *increase* of its electricity, it is said to be *positively* electrified; and when its potential is changed from zero by a *decrease*, it is said to be *negatively* electrified.

ELECTRIC MOVEMENT.—When a difference of electric potential exists between different bodies, or different parts of the same body, there is a constant tendency to equalization.

A state of equilibrium seems to be the natural condition of bodies, and to produce difference of potential requires, as we have seen, the exercise of force in the performance of work, by which this equilibrium is disturbed.

We find in other forms of energy, as gravity and heat, the same tendency to equilibrium, requiring the exercise of force to overcome it, as in the illustrations already given.

The restoration of equilibrium is always effected by a transfer of energy from the body having the greater to the one having the less energy; that is, from higher to lower potential.

In the case of gravity this transfer of energy carries

the body with it, as in the descent of a weight or the movement of water from a higher to a lower level. But in the case of heat and electricity, the energy may move while the body remains stationary; and it may be transferred from one body to another, or from one part to another of the same body. Thus the mass of metal, in the illustration given, transfers its heat energy to another mass; and in like manner, when a metal rod is heated at one end, the heat moves to the cold end.

Gravity apparently can move only by carrying the body with it, while heat moves through the body without producing change of position in its mass, like gravity.

A hot body transfers its heat to a cold one in its vicinity, but does not attract it; while gravity produces mutual attraction between all bodies, but is not transferred like heat from one body to another.

But in electrified bodies we have both kinds of movement. Like heat, electricity can move from one body to another, or from one part to another of the same body; and, like gravity, it can carry the body with it.

Hence we must distinguish between the movement of electricity and the movement of the electrified body. Electric movement, like heat movement, is from higher to lower potential. If one part of a conductor be electrified, the electricity instantly distributes itself over every part. If two insulated bodies, free to move, are placed in each other's vicinity, like the pith balls of the electroscope, the same tendency to equilibrium is shown by their mutual attraction.

Though only one ball be electrified, yet it is evident that their movement toward each other must be mutual, and in proportion to their mass, since action and reaction are equal: so that while the movement of the elec-

tricity is from the electrified to the non-electrified ball, that is, from higher to lower potential, the movement of the balls is mutual.

It will also be noticed that the movement of the non-electrified ball is opposite to that of the electricity. Hence, while electricity moves from higher to lower potential, bodies under its influence may move in either direction.

We have seen that when the two balls come into contact there is a transfer of electricity from the electrified to the non-electrified ball; equilibrium is established, and mutual repulsion follows, not only between the balls, but also between them and the electrified sealing-wax.

So long as a difference of potential exists there is mutual attraction; but when equilibrium is established there is mutual repulsion. The same results may be produced by numerous similar experiments, in which different substances and different methods may be employed. Hence we deduce the following important principle:

Electrified bodies at different potentials attract, while those at the same potential repel each other.

There can be no repulsion unless there is a difference of potential between the electrified bodies and their surroundings. For if the surrounding bodies were at the same potential as the electrified bodies, the repulsion would be neutralized by their reaction. Hence bodies at zero potential can show no repulsion. But in all cases of electrification there is a difference of potential created in the body, either above or below the original zero.

Indeed, attraction may account for the apparent

mutual repulsion of bodies at the same potential, since this difference of potential between the electrified bodies and their surroundings must produce attraction and tend to separate them.

But such outward attraction would not disprove the existence of repulsion, though it might account for some of its phenomena.

THE GOLD LEAF ELECTROSCOPE —As our investigations now require a more sensitive instrument than any which has yet been described, we here introduce the *gold leaf electroscope*.

Fig. 4—Gold Leaf Electroscopes.

The style represented at A, Fig. 4, is convenient, and easily constructed. It consists of a half-gallon tincture bottle, fitted with an ebonite stopper, through the center of which passes a small brass rod about five inches long, which terminates about three-fourths of an inch above the stopper in a brass disc about two inches in diameter, having a round rim about three-sixteenths of an

inch in diameter projecting from its lower surface, as shown in the enlarged section at *D*.

To the lower end of the rod is attached a thin cross-bar, about five-eighths of an inch long, which will pass easily through the neck of the bottle. And from this cross-bar are suspended two strips of imitation gold leaf, each five-eighths of an inch wide by $2\frac{1}{2}$ inches long. A small hole is drilled near the edge of the disc for convenience in attaching wires.

The leaves in this instrument lie close together, and, consequently, must always be electrified at the same potential; but in some experiments it is desirable to electrify them separately, and for this purpose a bottle with a wide neck is used, which will admit an ebonite stopper through which two rods can be inserted about an inch apart, and from the cross-bar of each a single leaf is suspended, the surfaces being parallel to each other. This style is represented at *B*, Fig. 4. The rods can terminate above in balls, or be bent outward and terminate in discs.

Electroscopes may be constructed with thin metal discs, attached to the glass opposite the leaves; strips of the same material extending down and connecting with the earth. Brass rods surmounted with balls are often used in the same way, as represented at *C*, Fig. 4; in which case a glass shade resting on a wooden base is more convenient than the bottle form.

The object in either case is to have conductors at zero potential near the leaves, which renders them more sensitive, and discharges them in case of too great divergence; thus preventing their adhesion to the glass, which is often troublesome. Annoyance from the latter cause is also obviated by using a bottle of globular form,

the sides of which are too remote to be touched by the leaves.

A brass cap, covering the glass above, as shown at *C*, is also used to screen the leaves from external electric influence, and wire screens are likewise used for the same purpose.

The use of the bottle, or glass shade, is to protect the leaves from currents of air which would destroy them. And the ebonite stopper is for better insulation, since the glass generally used for bottles and shades is of inferior insulating quality. The disc, or ball, and connecting-rod are for convenience in electrifying the leaves, which are the efficient part of the instrument.

The following experiment will illustrate its use:—Let the electrified sealing-wax touch the disc of electroscope *A*; electricity is instantly transferred to the disc, rod, and leaves, which are all good conductors, and the leaves, being free to move, and at the same potential, repel each other, and diverge.

If the disc now be touched with the finger, the electricity escapes to the earth, and the leaves, being reduced to zero, converge.

The sensitiveness of this instrument is so great that a chip of dry wood, less than a grain in weight, electrified in cutting, and dropped on the disc, produces divergence of the leaves. A wooden pen-holder, electrified by striking it lightly on the table, produces the same effect.

Hence, care must be observed to prevent the leaves from being torn by sudden, spasmodic movements, which are liable to occur when experimenting with highly electrified bodies in their vicinity.

MUTUAL EFFECTS OF FRICTION.—Thus far we have considered only the effect produced on the sealing-wax,

glass, or other substance electrified by friction, without reference to the effect on the substance by which it was rubbed. But since action and reaction are equal, it is evident that these two effects must, in some way, equal each other; that electricity, or its equivalent in some other form of energy, must be produced on the rubber as well as on the substance rubbed.

To test this, let a piece of flannel, after being used to rub a stick of sealing-wax, touch the disc of electroscope *A*, Fig. 4, and the leaves will instantly diverge, showing that the flannel has been electrified.

Substitute silk, fur, or any other substance used as a rubber, and the same result will follow. Let the various substances rubbed be also tested, and it will be found that electrification has been produced on both rubber and substance rubbed, at the same time, by the same process.

Now let a rubber, about the same size as the sealing-wax, be prepared, by wrapping a strip of wood in flannel and insulating one end with a piece of india-rubber tube.

Holding this rubber by the insulated end, let the sealing-wax be rubbed with it; and, keeping both still in contact, lay them carefully on the disc of the electroscope, so that both shall touch it at the same instant, and no divergence of the leaves will occur. Now lift off the sealing-wax and they instantly diverge; replace it and they converge. Lift off the rubber and they diverge, replace it and they converge again.

Let the experiment be made with any other two substances used to generate electricity by friction, as silk and glass, ebonite and fur, and similar results will be obtained.

It will also be noticed that the approach of either electrified body while the other lies on the disc causes the leaves to converge, while its withdrawal produces divergence.

There is often a slight divergence of the leaves when both bodies are in contact on the disc, due to the difficulty of producing perfect adjustment of contact, and also to the fact that the electric condition of one body may change more rapidly than that of the other, from imperfect insulation or other cause.

The amount of divergence is also liable to vary, the removal of one body producing greater divergence than the removal of the other. This difference is also easily accounted for by difference of mass, of conductivity, or other cause.

Hence we deduce the following rule: *When electricity is generated on two bodies by their mutual friction, the electricity of each is neutralized by the presence of the other.*

The effect of the mutual friction of the two bodies is to create a difference of potential by the transfer of electric energy from one to the other. As one gains what the other loses, the amount of energy on the two is not changed so long as they remain in contact, and hence the potential of the electroscope is not disturbed.

But let one of the bodies be removed; suppose it to be the one to which energy has been transferred, the potential of the remaining body being negative, there is instantly a transfer of energy to it from the disc and leaves, which thus become negative also.

The leaves, being both at the same potential, diverge by mutual repulsion; and that potential being less than zero, the divergence is increased by attraction from the higher potential of the glass and surrounding objects.

Replacing this body, let the one *from* which energy has been transferred be removed; the potential of the remaining body being positive, there is instantly a transfer of energy *from* it to the disc and leaves, making them positive also. Hence the leaves diverge as before, from mutual repulsion, and the divergence is increased by attraction from the *lower* potential of the glass and surrounding objects.

From this it will be seen that the effect on the electroscope is the same whether the potential of the electrified body be positive or negative. In either case there is mutual repulsion between the leaves, from their being at the same potential; and mutual attraction between them and surrounding objects, caused by difference of potential.

The indications of the electroscope furnish no means of distinguishing between positive and negative potential, being the same for both. And as this is true of most of the phenomena pertaining to these two states, it is difficult, in static electricity especially, to determine which phenomena are positive and which negative.

There is no such well-marked distinction between them as between the positive and negative states known as heat and cold; neither can we observe electric movement as we can heat movement; since heat moves slowly, while electricity moves with inconceivable rapidity.

But if we can show cause for an accumulation of electric energy at one point and for its absence at another, and show effects following such difference of energy, we then have proof of the positive and negative potential of the different points, which may be accepted as reliable.

Such proof will be furnished hereafter, and the further consideration of this question must be deferred till the examination of other phenomena shall enable the student to comprehend such proof.

CHARGE DEFINED.—The term *charge* is used to express the condition of an electrified body when its potential is above or below zero. If its potential has been raised above zero by receiving electricity, it is said to be *positively* charged ; but if its potential has been reduced below zero by the removal of electricity, it is said to be *negatively* charged.

Hence we speak of a high negative charge in the same sense as we speak of intense cold, meaning an intensity of the negative condition caused by the absence of heat.

CHAPTER III.

THE NATURE OF ELECTRICITY.

THE CONSERVATION OF ENERGY.—A clear understanding of that great doctrine of modern science, known as *the conservation of energy*, lies at the foundation of a correct knowledge of electricity and electric phenomena. Hence a brief examination of its principles will not be out of place here.

Energy is a universal property of matter. It is the principle of life and movement in matter in distinction from matter itself, inseparably connected with matter and yet distinct from it: heat as distinct from the heated body; electricity as distinct from the electrified body; life as distinct from the living body.

Like matter, it manifests itself in various forms, as gravity, cohesion, chemical affinity, light, heat, electricity. Like matter, its quantity in the universe is fixed and definite, and cannot be increased or diminished. And hence, like matter, it is indestructible.

It may be transmuted from one form into another, but in the transmutation there is no loss. One form may re-appear in many forms, or the many be reduced to the one.

In our experiments, muscular energy has been expended to produce electric energy; but the energy produced must equal that which produced it, if the doctrine of the conservation of energy is true. And since

it is evident that only a very small part of the muscular energy expended would be required to move the pith balls, the balanced rod, or the gold leaves, the remainder must be accounted for.

This is easily done when we consider, first, that the electric energy was equally divided between the rubber and the substance rubbed; secondly, that only a small part of the electric energy was used; that the electricity generated was sufficient for the performance of the same work many times in succession, either with the rubber or substance rubbed; and that a number of pith balls, placed on all sides of the electrified body, might have been subjected to its influence. Thirdly, we must consider the amount of electricity lost from contact with the surrounding air; and, lastly, that the amount of heat energy generated by the friction was probably equal to the electric energy.

If the expended energy had been produced by a descending weight, which should cause a glass or ebonite cylinder to revolve in contact with a rubber, and the sum total of the heat and electricity had been recovered in the form of work which could be estimated, it would be found so nearly equal to the number of foot-pounds expended by the descending weight, that whatever difference existed could easily be accounted for by the friction of the machinery and other causes.

Experiments of this kind have been actually performed, and the results verify the above conclusion. Similar experiments have also been made with other forms of energy, and like results obtained; so that the principles of the conservation of energy are now

well established, and universally recognized in all practical work.

Another illustration may render the subject more clear. A pound weight raised to a height of 20 feet has acquired 20 foot-pounds of energy; and, in descending to its former level, can accomplish 20 foot-pounds of work; as in raising to the same height another weight of nearly equal mass. But if stopped in its descent at a level of 10 feet, it has expended only 10 foot-pounds of energy, and has still a reserve of 10 more.

It is evident, that to raise the weight in the first place required the expenditure of 20 foot-pounds of energy; and that though this energy was consumed in the process, and had disappeared, it was not lost, but merely stored up, ready to be expended, either at once, by the weight descending the entire distance, or in detail, as when stopped half way or at any other point. If it had descended but one foot, it would still have a reserve of 19 foot-pounds of energy.

It will be noticed that the second weight, raised by the descent of the first, is required to be of less magnitude, since part of the energy must be expended in overcoming friction and inertia. For if it were of equal magnitude, the force expended would exceed the force stored up; since it must perform not only the same work, but the added amount for friction and inertia; in which case it would be possible to create force, and the doctrine of the conservation of energy would cease to be true.

It is immaterial whether the descent of the one pound raises a small weight to the height of 20 feet, or a large weight to the height of one foot; which it can be

made to do by a system of ropes and pulleys. The 20 foot-pounds of energy expended must exactly equal the 20 foot-pounds stored up; and the height through which the large weight is raised is to that through which the small weight descends in the inverse ratio of the mass of each.

In all electric work, of whatever nature, the same principle will be found to hold true; gravity potential in this case representing electric potential in electric work. Mechanical work may re-appear as electric work, or electric as mechanical work; the energy produced being always, in some form, equal to the energy expended.

HEAT, LIGHT, AND ELECTRICITY COMPARED.—The weight of evidence goes to show that electricity, like heat and light, belongs to that kind of energy known as molecular; and whatever is known as to one kind of energy may, by analogy, be inferred as to other kinds of the same class, with such modifications as distinguish different species of the same genus.

There is ample proof that heat is a mode of molecular motion. Not that the heat *produces* the motion, or the motion the heat, but that it *is* motion; that the molecules of matter being thrown into a certain kind of motion, the result is the sensation known as heat.

According to the universally accepted theory of light, it is another species of motion of the same kind; and there are indications that light and electricity are identical. But, if not identical, we may at least assume that they are closely allied to each other.

We find also that the same causes, acting at the same time, on the same bodies, and under the same

circumstances, produce both heat and electricity, in numerous instances; in others, equally numerous, both heat and light, and in others, heat, light, and electricity.

The simultaneous production of heat and electricity is seen in the examples already given of bodies electrified by friction, of which heat is also a necessary result.

Another prominent instance is the action of the electric generators known as dynamos; in which the evolution of heat is such that special provision for cooling has to be made, to prevent injury. Here mechanical action is the agent.

In the galvanic battery we have a well-known instance of the production of heat and electricity by chemical action; as a certain amount of heat, more or less perceptible, is always a result.

Instances of the simultaneous production of heat and light are numerous and well known, as the heating of an iron rod, which becomes luminous when the temperature rises to a certain degree; whether it be heated by friction, as of a shaft and journal, or by the chemical action of a furnace.

The dynamo and galvanic battery have been referred to as producing both heat and electricity. When a current of this electricity, of sufficient intensity, is passed through a conductor of high resistance, as a fine platinum wire, or a carbon filament, they become luminous by incandescence; and when passed through two sticks of carbon slightly separated, we have light of great intensity; and there is, in both instances, the evolution of intense heat. These are perhaps the most striking examples which can be given of the sim-

ultaneous evolution of heat, light, and electricity from the same causes.

In the thermo-electric battery we have an example of the direct production of electricity by heat.

POLARIZED LIGHT AND ELECTRICITY.—Experiments with polarized light, made by Faraday and others, furnish strong evidence of the close alliance, if not actual identity, of light and electricity.

It is known that light, from certain peculiarities of reflection and transmission, undergoes a change, so that when subsequently transmitted, its action is different from that of the original transmission, and this change has been termed *polarization*.

Let a plate of tourmaline be so placed that a ray of light falling on it shall be transmitted at right angles to a particular direction within the crystal, known as its optical axis. Then let another tourmaline plate be so placed with reference to this one that their optical axes are parallel, and that the ray shall pass through both and form a bright spot on a screen beyond.

Now let either plate be turned, so that their optical axes are no longer parallel to each other, but still at right angles to the ray; the bright spot on the screen will fade as the angle increases, till at 90 degrees it will disappear. Continuing the rotation, it will re-appear, increasing in brightness, till, at 180 degrees, it is entirely restored; then fading again till extinguished at the end of the third quadrant, and again increasing in brightness till restored at the end of the fourth quadrant, or original position.

This alternation of brightness and extinction depends on the relative angular position of the plates. Let either of them be turned in either direction, and

the same result follows; but when both are turned in the same direction, there is no change in the brightness, and no extinction of the light. Substitute one for the other, and the same results are obtained.

It is evident, then, that the light in passing through the first plate has undergone a change which affects its transmission through the second, in any position except when the optical axes of both are parallel; extinguishing it entirely when they are at right angles to each other.

It is also found that this effect, termed polarization, occurs to light transmitted through or *reflected from* any transparent medium, as glass, selenite, Iceland spar, and various liquids. Polished metals also produce the same effect on reflected light. And this reflection or transmission takes place at a certain angle, known as the polarizing angle, which varies in each substance by a certain definite amount.

Now let the ray be transmitted through, or reflected from, a small piece of glass of suitable size or shape, placed at the proper polarizing angle, and let the plates be turned till their optical axes are at right angles, so as to produce extinction; then let the glass be subjected to a powerful electric strain and the extinguished light will re-appear, continue during the electric action, and disappear when it ceases; which shows that this electric action has counteracted the effects of polarization.

Similar experiments with various substances, too numerous to detail here, show similar results.

Without anticipating another branch of our subject, it may be stated here, that electricity and magnetism are so closely allied that whatever affects one must have some important relation to the other.

Recent experiments have demonstrated that unusual disturbances in the variation of the magnetic needle are coincident with unusual disturbances in the sun, in connection with the phenomena known as sun spots; and that the telegraph and telephone are, at such times, seriously disturbed by what are known, technically, as "electric storms"; that is, unusual disturbances in the earth's electricity shown in the phenomena known as *earth currents*.

It has also been found that these solar disturbances are periodic; and that these periods, for the last hundred and fifty years, correspond almost exactly with the periods of unusual variation of the magnetic needle.

Since the sun is our chief source of light and heat, since they are, in fact, the result of the constant disturbance of the elements of that body; and since, when this disturbance assumes an unusual phase, there is, coincident with it, an unusual disturbance in the earth's electricity, it must be accepted as strong proof of a common origin of heat, light, and electricity.

We have heat, light, and electricity derived from friction, from chemical action, from magnetic action, and from the sun. We have heat producing electricity, and electricity producing heat and light; and we have electricity neutralizing the polarizing effect of light. The evidence of identity then becomes cumulative, while that of close alliance amounts to demonstration. Hence we may infer certain facts in regard to the nature of electricity from what we know of similar facts in regard to the nature of light and heat. And we are also warranted in the conclusion, that a well supported theory of light or heat requires but little modification to adapt it to electricity.

This much we certainly know, that they all are forms of energy and that they radiate from the centers where they are generated. Hence the term *radiant energy* is equally applicable to each.

THE WAVE THEORY.—It has been assumed that a subtle medium, termed *ether*, pervades all space; that it is so attenuated that it can insinuate itself between the grosser molecules of material bodies; so that solids of the finest and closest texture, as well as liquids and gases, are pervaded by it; and that light, and probably electricity, are due to waves or undulations of this ether. The evidence of the existence of such a medium is almost wholly negative, and, like all negative evidence, unsatisfactory. The assumption presupposes the necessity of its existence.

It has been stated that energy is a universal property of matter, and the converse may be accepted, that energy cannot exist without matter. And since light, coming from the sun, must traverse the interplanetary spaces, there must be matter there; else we shall be compelled to admit that energy can exist without matter, which is contrary to all our experience.

The earth is surrounded by an atmosphere, to the limits of which we cannot penetrate. In 1822, Dr. Wollaston made a careful mathematical calculation, as the result of which he claimed to have demonstrated that the earth's atmosphere must have limits, beyond which it cannot exist. And this apparent demonstration was accepted as authority, and remained unchallenged for half a century. Meantime the wave theory of light became prominent, and a medium being one of its fundamental principles, the existence of the ether was assumed, and is now generally accepted.

But the researches of modern science have swept away many of the errors of the past, and it is not impossible that Dr. Wollaston's demonstration may share the same fate. Many eminent scientists, who have made experimental investigations on the subject, hold that the expansibility of the earth's atmosphere is unlimited; among whom may be cited Grove, Gassiot, Geissler, and Dr. Andrews. And W. M. Williams, in his work, "*The Fuel of the Sun*," claims to have discovered a serious error in Dr. Wollaston's calculations, which vitiates his conclusion.

The assumption of these writers is that an atmosphere, the same as that of our earth, pervades all space; that in the interplanetary spaces it becomes exceedingly attenuated; and that each of the heavenly bodies attracts and surrounds itself with a portion of it; the extent and density of which is in proportion to the mass of the body.

The high degree of vacuum which can now be attained by improvements in the air-pump, seems to demonstrate, that while electricity will pass more freely through rarefied air, on account of the reduced resistance, than through air of ordinary density, it must still have a medium in which to travel; and that its passage through an absolute vacuum, or space devoid of any known material substance, is highly improbable. But as the best attainable vacuum is still only an approximation to an absolute vacuum, the full demonstration of **this** point has not yet been reached.

The existence then of some elastic medium, by which the two forms of radiant energy, known as light and heat, can traverse the interplanetary spaces, is not questioned. Nor does the theory of the unlimited ex-

pansion of our atmosphere conflict at all with the theory of the universal existence of ether, since the theory of ether is that it permeates all material substances.

The wave theory assumes that radiant energy is transmitted by the undulations of some medium; that an impulse originating at any center of energy, as the sun, produces a wave which traverses this medium with inconceivable velocity, till it reaches some distant point, as the earth; and that the constancy of such impulses at every point on the sun gives rise to the phenomena of solar light, heat, and electricity.

In like manner we may assume any other center of energy, as a red-hot metal ball, radiating light and heat; a stick of ebonite, excited by friction, radiating electricity.

It is also assumed that the impulses radiate in straight lines, while the undulations occur at right angles to those lines.

To illustrate:—Drop a pebble on a smooth sheet of water; the impulse creates waves which radiate outward in widening circles. The pebble has depressed the water at the point where it struck, forcing the adjacent water outward, and causing it to rise above the general level; then the downward impulse of this wave, sinking under the force of gravity, raises the original center, and also produces, by its outward impulse, another wave beyond, as it descends by its inertia below the general level.

As the water oscillates vertically above and below the level, each successive impulse produces a new wave, while the same process goes on in the outward waves, creating new waves beyond, in ever widening circles,

till the force of the original impulse has been exhausted, and the water returns to its original level.

Now it will be perceived that there is no transfer of the water from the center outward beyond the length of the first wave. Part of the water forced outward by the original impulse flows back again, while another part flows outward, producing a new wave. The water is then under the influence of two forces, one horizontal, the other vertical, acting at right angles to each other; the horizontal producing the wave length, that is, the distance from crest to crest, or from hollow to hollow, while the vertical produces the height, that is, the vertical distance from hollow to crest, or from crest to hollow.

In a similar way, it is supposed, occur the undulations of the assumed elastic medium, with this exception, that the waves on the water occur in the same horizontal plane, radiating outward in concentric circles, while those in the elastic medium occur in any direction in which they are free to move; radiating outward in concentric spheres, if wholly unrestrained; or in sections of spheres or spheroids, if limited and starting from impulses at various points on any surface, either spherical, like that of the sun, or plane.

Having taken an illustration from a liquid, illustrations from solids will also be in point.

If a long rope, stretched lengthwise, with plenty of slack, be held at one end, and jerked rapidly up and down, it will be thrown into waves, which will run along its entire length.

Here it is evident that while the impulses given at one end travel in waves to the other, the rope, as a whole, remains stationary; successive portions acting

as yielding levers to transmit the impulse along its length.

If one end of a lever be depressed below a horizontal, it receives a forward as well as downward movement, in the arc of a circle, its opposite end receiving an upward and backward movement. In this way each successive portion of the rope oscillates horizontally as well as vertically, modified by the difference between a yielding and a rigid body.

Let a number of elastic balls be suspended in a straight line in contact with each other. Draw back the outer ball at one end of the line and let it swing against the adjoining ball; the impulse will be transmitted along the line, and the outer ball, at the other end, will swing off to nearly the same distance as that through which the first ball swung, all the others remaining stationary.

Here the impulse is transferred from ball to ball by virtue of their elasticity. When number one impinges on number two the impact changes its shape slightly to that of a spheroid; as it resumes its shape it imparts the impulse to number two, by which it is imparted to number three, and so on through the line. But action and reaction being equal and opposite, there is no perceptible movement till the last ball is reached, which swings off, since there is no ball to react against it. *The impulse travels, but the line remains stationary.*

Here, also, it will be perceived that there is a radial force acting at right angles to the horizontal force, much the same as would result from a similar impact if each ball were hollow, and its surface composed of an infinite number of semicircles, joined at the points of impact.

Now the molecules of a metal rod may be compared to an infinite number of these lines of balls; and it may be assumed that a heat impulse, or an electric impulse, given at one end, moves along these lines in some way analogous to that in which the impulse moves along the lines of balls.

We are not obliged to confine ourselves to any specific method of movement; but may suppose a wave movement, similar to that which takes place in the slack rope, or on the water, if it shall seem to accord best with known facts and phenomena.

In the polarization of light, it is supposed that the waves assume a certain phase, in conformity with the special arrangement of the molecules of the crystal. Hence if the crystals are cut from the same block, and placed in the same position, the phase will be the same for each, and the light will pass through. But if the second is turned at right angles to the first, the phase produced by passing through the first will not be in conformity with the arrangement of the molecules in the second, and hence the light cannot pass through.

Suppose the arrangement of the molecules to be in layers, or strata, like the sheets composing a ream of note-paper, placed in a vertical position; the waves of ether would assume a vertical phase, and, meeting the second crystal, placed in the same position, would pass through. But if the second were turned, so as to bring its strata to a horizontal position, the vertical waves would be broken, and could not pass through.

Instead of the ether we may suppose the molecules themselves thrown into waves, whose phase would conform to the structure of the crystal, and the same result would evidently follow.

There is no reference, in this supposed case, to any visible stratification of a crystal, as the experimental ray is usually admitted at right angles to such stratification; the reference is to an invisible arrangement of the molecules.

The same course of reasoning is applicable to heat, or to electricity, but the phase of the heat wave, or the electric wave, may be different from that of the wave of light, so that a substance opaque to light, as copper, might allow the free passage of heat or electricity; or a substance transparent to light, as glass, might obstruct their passage.

And the medium in which the electric energy travels may be the ether which is supposed to pervade the different kinds of matter; or the matter itself, in any of its various forms, solid, liquid, or gaseous: as it has been shown that undulations may take place in each of them.

CONDUCTIVITY FOR HEAT AND ELECTRICITY COMPARED.—It is very remarkable, and must be something more than mere coincidence, that conductivity for heat and electricity is nearly the same in the same substances. A good heat conductor is a good electric conductor; a non-conductor of heat is a non-conductor of electricity. So that if we know either the conductivity or resistance of any substance for heat, we have, practically, its conductivity or its resistance for electricity. This will appear from the table following, showing the results obtained by Wiedmann and Franz.

Hence if heat and light are modes of motion, traversing various substances by undulations, we are warranted in assuming the same with reference to electricity.

COMPARATIVE CONDUCTIVITY OF DIFFERENT SUBSTANCES FOR HEAT AND ELECTRICITY, AS GIVEN BY WIEDMANN AND FRANZ:—

Substance.	Heat Conductivity.	Electric Conductivity.
Silver	100	100
Copper	74	73
Gold	53	59
Brass	24	22
Tin	15	23
Iron	12	13
Lead	9	11
Platinum	8	10
German silver	6	6
Bismuth	2	2

Other observers place the electric conductivity of some of these substances much higher, making the conductivity of copper nearly equal to that of silver.

If the electric wave has its own peculiar structure, it is evident that a substance whose structure is adapted to it, or whose molecules easily adapt themselves to it, would be a conductor; while a substance whose structure is not so adapted, or whose molecules resist such adaptation, would be a non-conductor.

An attempt to insert a No. 36 screw into a No. 30 screw hole will fail, because the threads of the screws are not adapted to each other. But let the same screw be inserted into some yielding substance, as soft wood, and the substance adapts itself to the structure of the screw; or, as we say, it cuts its own thread; while a rigid substance like iron resists such adaptation.

Something analogous to this may constitute the difference between conductors and non-conductors, and may also be the cause of other electric phenomena of equal importance.

THE SPARK AND SNAP.—As already stated, every substance offers a certain degree of resistance to the passage of electricity, and a result of this resistance is the generation of heat, often accompanied with light, and this effect varies as the resistance.

Platinum is a metal of high resistance, while that of copper is very low; and a fine platinum wire will be brought to a white heat by an electric current which would scarcely change the temperature of a copper wire of the same size.

Air offers such high resistance that the passage of electricity through it always produces both heat and light, in the form of a bright spark. This occurs not only when an electric charge passes through several inches of it, but through the thinnest film; the presence of heat, as well as light, being demonstrated by the lighting of gas by a spark less than $\frac{1}{8}$ inch in length.

A sudden condensation of the air, forced forward and laterally by the charge, has been suggested as the probable cause. If such condensation takes place, heat would certainly be the result, as when air is compressed by mechanical means. And perhaps it would be accompanied by light, though this is not probable, as combustion and incandescence are the only known means of producing artificial light besides that now under consideration, either of which would imply the presence of some other substance besides air. But the hypothesis seems to assume the passage of some material substance through the air to produce the condensation, of which there is no evidence.

But if, instead of condensation, we suppose undulations to take place, giving great intensity of motion, as the electric impulse, darting forward with incon-

ceivable velocity, suddenly forces the resisting air into the phases of the electric waves; then the generation of those other modes of motion, known as heat and light, might easily be the result.

A sharp sound, varying from an insignificant snap to a deafening report, always accompanies the spark. On the condensation theory this is accounted for by the sudden displacement and reflux of the air. But since sound, like heat and light, is another mode of motion, occurring chiefly in the air, it is evident that the wave theory will best account for it; the electric impulse giving rise to these different modes of motion.

THE DUAL THEORY.—We have already seen, in experiments with the pith ball electroscope, that the balls may be attracted and repelled by electrified glass, sealing-wax, and various other substances.

Let an electrified glass rod approach one of the balls; the ball is attracted, and, after contact, repelled. Now let an electrified stick of sealing-wax be brought near, and the electrified ball, which was repelled by the glass, is attracted by the wax. Or let the ball be first electrified and repelled by the wax, and it is attracted by the glass.

Further experiments show that the same results can be produced with other substances; glass representing a certain class of substances, which show similar electrification, and sealing-wax and resin another class, which shows opposite electrification to that of glass.

Hence it has been assumed that there are two kinds of electricity. One kind generated on the class of substances represented by glass, and the other on the class represented by resin. The former was once designated as *vitreous*, and the latter as *resinous*; but the term

positive is now used instead of vitreous, and *negative* instead of resinous. Used in this way, these terms have no reference to a difference either in quantity or intensity; they express only a supposed difference in *kind*, not in *degree*.

-This doctrine of the dual nature of electricity was first proposed by Dufaye, and has since been strongly maintained by many eminent scientists. Deschanel, speaking of the phenomena under consideration, says: "These phenomena clearly show that the electricity developed on the resin is not of the same kind as the electricity developed on the glass."

Now the only thing "*clearly shown*" is the difference in the *substances*, not in the *electricity*. For we have precisely the same electric phenomena of attraction and repulsion with the glass as with the sealing-wax; but a third substance, the electrified pith ball, is attracted by one and repelled by the other; a result which it would seem more reasonable to attribute to the difference *known* to exist between the *substances*, than to a difference *supposed* to exist in the electricity. For it has already been shown that different causes, as conductivity or resistance, influence the intensity of electrification on different substances. Other causes also, as a difference of temperature or mass, of hardness or softness, density or porosity, doubtless contribute to the same result.

But considering the quality of resistance alone, the potential of any non-conductor, as glass, is liable to vary greatly on different parts of its surface, when electrified by friction; and to differ from the potential of sealing-wax, similarly produced on different parts of *its* surface.

The friction of the same rubber is also greater on a substance like sealing-wax, whose surface is soon softened by the heat generated, than on a smooth, hard substance like glass, which is not affected in this way.

And, as already shown, *difference* of potential produces attraction, while *equality* of potential produces repulsion, between bodies. Hence the attraction by the sealing-wax, of the pith ball electrified by the glass, is a necessary result of difference of potential; while its repulsion by the glass follows from equality of potential. And the same will be true of the ball electrified and repelled by the wax and attracted by the glass.

But if a difference exists in the kind of electricity produced by the different classes of substances, we should expect that difference always to manifest itself whenever one of either class is employed as a generator.

But this is only true in a general way, to which the exceptions are very numerous; for it often happens that glass and sealing-wax, or other substances belonging to the different classes, when rubbed with the same rubber, exhibit the same electric qualities. The same result also will often follow where different kinds of rubbers are employed, as silk on one substance and woollen on the other.

Such results are inconsistent with the theory of two electricities; but are easily accounted for by a difference, or an equality of potential, which we know is liable to exist.

Hence, preference must be given to the doctrine of *one* electricity, originally proposed by Franklin; simple and plain, like truth itself, and in strict accord with all electric phenomena; whether pertaining to static electricity, or to electricity under other forms.

CHAPTER IV.

INDUCTION.

IT is noticeable that in all our experiments thus far the electrified body acts on the other bodies *before* there is any actual contact. The knife-handle attracts the spoon; the sealing-wax, ebonite, or glass attracts the balanced rod or the pith ball while separated from them. And when either of these electrified bodies approaches the gold-leaf electroscope, there is first a divergence of the leaves before contact occurs.

It will also be noticed that this effect increases or diminishes as the distance is increased or diminished. And, further, that while the interposition of different substances, as glass, paraffin, ebonite, air, wood, metal, produce great variations in the effect, none of them wholly prevent it.

There is evidently, then, an invisible influence extending to a certain distance from the electrified body in every direction, and affecting everything within its sphere, and this effect is called *induction*.

When an electrified body is brought near the disc of the electroscope without touching it, the leaves diverge, and on its removal converge again, showing no permanent effect. But if it is allowed to touch the disc, the leaves are electrified, and remain divergent after its removal.

But if, instead of touching the disc, it be held near

enough to produce divergence, as at *A*, Fig. 5, and, while in that position, the disc be touched with the finger, as at *B*, the leaves will converge, and remain so as long as the electrified body is held near; but on its removal as at *C*, they will diverge, and remain divergent, the same as after contact of the electrified body with the disc.

Fig. 5—Induction Illustrated.

Here, then, is electrification by induction, without any transfer of electricity by contact. How can this be accounted for?

When the electrified body is brought near, whether its charge be positive or negative, the effect of induction is to produce a temporary change of the potential of the electroscope, and the leaves diverge.

If the charge of the electrified body be positive, electricity is repelled from the disc to the leaves, and they diverge, being positively electrified to the same potential, and hence mutually repellent, and also attracted by the lower potential of surrounding bodies.

But if the electrified body be *negatively* charged,

electricity is attracted from the leaves to the disc, and they diverge, being negatively electrified, and mutually repellent, as before, and attracted by the *higher* potential of surrounding bodies.

Now, when the disc is touched with the finger, and thus connected with the earth, if the charge is *positive*, the potential of the electroscope is changed by the escape of electricity to the earth under the influence of the electrified body, and the leaves converge. But if the charge is *negative*, the potential of the electroscope is changed by the *attraction* of electricity *from* the earth, and the leaves converge as before, equilibrium being restored between the disc and leaves in each case.

The leaves remain convergent so long as the electrified body is held near; the electroscope being still under the influence of the force by which the change of potential was produced; which is evidently just equal to the repelled energy in the first instance, and to the attracted energy in the second. But when the electrified body is removed, this equilibrium is disturbed, and the leaves diverge under the influence of mutual repulsion and outward attraction, as already explained.

This experiment proves that a body connected with the earth, and under the influence of induction, may differ in potential from the earth, and is not necessarily at zero potential from its earth connection. For it is evident that such difference of potential existed during the connection of the electroscope with the earth, else it could not have become manifest when the connection was severed and the inductive influence removed. For when the electrified body is removed *before* such connection, the leaves converge, but when removed *after* it has been made and severed, they remain divergent:

showing that the difference of potential was created and existed *during* the earth connection.

This point has an important bearing on phenomena to be considered hereafter, in regard to which prominent writers have been betrayed into serious mistakes from having overlooked it.

INFLUENCE OF DISTANCE.—It is important to notice, that when the electroscope has been charged by induction in this manner, and the electrified body is again brought near, the leaves continue to converge as the body approaches, and come together when it is in the same position as when the disc was touched with the finger. A nearer approach produces divergence, which increases as the body is brought still nearer.

Let it now be gradually withdrawn, and the leaves gradually converge and come together, when the body reaches the same point, as before. Further withdrawal produces divergence, which continues to increase, and reaches its limit when the body is wholly removed.

If the electroscope be placed at various points, equally distant from the electrified body, the effect of induction will be the same, so long as the same distance from the earth and surrounding objects is maintained. Hence it is evident that electric energy, like other forms of radiant energy, as light and heat, radiates equally in all directions when not interfered with by other influences.

Suppose the electrified body to be a small globe, entirely removed from the earth, and surrounded with a perfectly homogeneous medium, it would be the center of a sphere of inductive influence. And suppose the lines of force radiating from it to be cut by the surfaces of two imaginary concentric spheres of differ-

ent sizes, one placed outside of the other, and having the electrified globe for their common center.

Since the surfaces of spheres are to each other as the squares of their radii, and since the radii measure the distances from the center, the surfaces are to each other as the squares of their distances from the center.

But as each surface embraces all the lines of force, the intensity of force on equal surface areas of the two spheres would be in the inverse ratio of their entire surfaces; and hence would vary inversely as the squares of their distances from the center.

Hence, electric induction varies inversely as the square of the distance.

Practically the conditions of the supposed case are never exactly fulfilled; but that does not affect the correctness of the principle, which is the same in electricity as in light and radiant heat.

CYLINDER ELECTRIFIED BY INDUCTION.—The effect of induction may be further illustrated by an insulated cylinder of conducting material, placed between two spheres of similar material, one insulated, and the other connected with the earth by a chain, as shown in Fig. 6; the cylinder having mounted on it three pith-ball electroscopes, connected with it by conductors.

If the insulated sphere, *A*, be positively electrified, electricity will be repelled by induction from the end of the cylinder next *A* to the end next *B*. And since *B* is connected with the earth, the electricity accumulated on the end of *C*, next to it, will repel to the earth from *B* an amount equal to the positive charge on *A*.

Hence the pith ball next *A*, being negative and *A* positive, is attracted by *A*, while the one next *B*, being

positive and B negative, is attracted by B ; but the central ball, being neutral, remains unmoved.

If the sphere, A , be negatively electrified, these conditions will all be reversed. Electricity will be attracted to the end of C next A , and a positive charge, equal to the negative on A , attracted from the earth to B . Hence the balls will assume the same positions as before.

Fig. 6—Cylinder Electrified by Induction.

Similar inductive effects can be produced on the cylinder by the sphere A alone, but less marked than when two spheres are used; and, for such an experiment, tin-foil electroscopes are better than those made with pith balls, being more sensitive.

THEORY OF INDUCTION.—It is not known how inductive force is transmitted. The hypothesis has been advanced that it is by a certain strain of the medium; as when a weight is lifted by a rope or pushed by a pole, the energy is transmitted in one case by the tension of successive portions of the rope, and in the other by a compression of successive portions of the pole. In either case the energy or *stress* produces a *strain*, which

runs through the substance of the medium till it reaches the object, and the continued stress produces continued strain. Something analogous to this, it is assumed, takes place in the transmission of electric energy by induction.

This hypothesis has the sanction of eminent authority, and may assist us in arriving at a solution of the problem. Gordon says: "If electric induction were a 'direct action at a distance,' we should expect that it would be transmitted equally through all insulators. One of the strongest arguments for supposing it to be a strain of the particles of the insulator is found in the fact that different insulators transmit it with very different strengths."

"Induction, so far from being a 'direct action at a distance,' is most certainly transmitted by the particles of the dielectrics, and is affected by almost every molecular change which may occur in them."

And he defines *strain*, as here used, to mean "an alteration of size or shape," including "all alterations of volume," "all twistings and bendings, and all vibratory motions other than those of a rigid body as a whole."

The wave theory agrees with the views here expressed; for we have only to conceive that this "strain" consists in a "vibratory motion," that is, in undulations of the medium.

It is also in accordance with the analogy of similar transmission of other forms of radiant energy. And, if all energy has a common origin, it is reasonable to suppose that the transmission of its different forms would present striking analogies.

INFLUENCE OF DIELECTRIC.—In order to observe

induction there must be two or more bodies at different potentials placed in each other's vicinity, and these must be separated by an insulator; for, if separated by a conductor, equilibrium would at once be restored, and induction could not take place.

Insulators through which induction takes place are called *dielectrics*, from the Greek $\delta\iota\alpha$, through. Air was the dielectric between the electroscope and electrified body, and between the spheres and cylinder, in the experiments already given.

Now, since conductors permit electricity to pass through them easily, while insulators resist its passage, there must be some peculiarity in the nature or arrangement of the molecules which makes two bodies of the same class similar in this respect, while two of opposite classes are dissimilar.

Hence we can easily conceive that when two insulated conductors, at different potentials, are brought into contact, the undulations of their molecules would assume the same phase, and equilibrium take place; but that when those undulations are transmitted through a dielectric, they undergo such a change that, the phases of the undulations not being the same, there is a repulsion instead of an intermingling, which results in creating opposite potentials in adjacent parts, on either side of the dielectric, the negative of one being equal to the positive of the other.

And since in the transmission, part of the energy is consumed in overcoming the resistance, difference of potential, on opposite sides, must result from this cause also.

If either conductor be removed, still remaining insulated, the equilibrium of each will be restored, and its

potential be found the same as before it was brought within the sphere of inductive influence, showing that no permanent effect has resulted.

Hence it will be seen that the effect of induction is opposite to that of contact; the latter producing permanent equilibrium between conductors, while the former produces temporary disturbance of equilibrium.

SPECIFIC INDUCTIVE CAPACITY.—It has already been stated that electric induction takes place through all substances, but in different degrees; and, since it is found that each has an inductive power peculiar to itself, this property is called its *specific inductive capacity*.

The importance of this subject will be understood when it is considered that it affects enterprises involving large capital, public convenience, and public safety; as in the transmission of electric energy by insulated conductors, as telegraph and telephone wires, ocean cables, and electric light wires; including the important question of underground transmission in cities.

Hence, for the last forty years, it has engaged the attention of such men as Faraday, Boltzmann, and many others, including the earlier researches of Cavendish, who seems to have been the first to investigate it, but whose experiments on this subject have only recently been published.

The general method of investigation is as follows:—The inductive capacity of dry air at the barometric pressure of 760 millimeters (29.92 inches) and at the temperature of 0° C. (32° Fahrenheit) is made the standard unit by which the inductive capacities of all other substances are estimated.

To illustrate:—Suppose we have two insulated metal plates, *A* and *B* (Fig. 7), separated by an air space *C*; let *A* be electrified and *B* connected with the disc of an electroscope. First note the amount of divergence of the leaves; then let a plate of glass, cake of paraffin, or any other insulator which will exactly fill the space

Fig. 7.—Specific Inductive Capacity Illustrated.

C, be introduced between the plates, and note the divergence of the leaves now, as compared with the former divergence.

As this insulator has displaced the air, it is evident that its inductive capacity, as compared with air, is shown by the difference in the divergence of the leaves.

If that divergence has increased, then the power of this insulator to transmit electric influence—that is, its specific inductive capacity—is greater than that of air; otherwise, it is equal to, or less than that of air.

From this we see that *specific inductive capacity varies inversely as insulation*. Hence this property is almost infinite in the best conductors; while in the best insulators it is the reverse.

By methods similar to the above, with the aid of improved instruments, to be described hereafter, the specific inductive capacities of a number of substances, including the principal insulators, have been carefully estimated by Boltzmann, Gordon, and others: and from the results obtained by them the table on the next page has been prepared, in which the general averages are given.

The results obtained by different observers differ so widely that they can only be regarded as approximate, and will undoubtedly require future correction, when improved methods shall give greater accuracy.

The table shows the electric resistance of glass to be much less than that of ebonite; the inverse ratio being 5.87 to 289: and this is doubtless true of glass, in the average. But, if the best insulating glass were compared with the best insulating ebonite, the ratio might require to be reversed. Ebonite, when subjected to a powerful electric strain, seems to yield gradually, and allow the electricity to *creep* through it; and, by continued strain, its electric resistance soon becomes permanently impaired: while the best insulating glass rigidly resists, and suffers fracture before yielding.

But, according to Gordon, the electric resistance of glass also becomes somewhat impaired by long use; or,

which is the same thing, its specific inductive capacity is increased. All of which goes to prove that electric transmission depends on molecular structure.

SPECIFIC INDUCTIVE CAPACITIES OF VARIOUS SUBSTANCES.

Standard.

Air at 0° C. temperature and 760 mm. pressure, 1.0

Solids.

Paraffin,	2.09
Caoutchouc,	2.23
Gutta-percha,	2.46
Shellac,	2.85
Ebonite,	2.89
Sulphur,	2.95
Resin,	3.6
Glass, average of various kinds,	5.87

Liquids.

Bisulphide of carbon,	1.81
Petroleum,	2.05
Oil of turpentine,	2.19

Gases.

Hydrogen,	H,	at 0° C. and 760 mm.,	.99941
Carbonic oxide,	CO,	“ “	1.00001
Marsh gas,	CH ₄ ,	“ “	1.00035
Carbonic dioxide,	CO ₂ ,	“ “	1.00036
Nitrous oxide,	NO,	“ “	1.00039
Olefiant gas,	C ₂ H ₄ ,	“ “	1.00072

CHAPTER V.

ELECTRIC DISTRIBUTION AND CONDENSATION.

EQUIPOTENTIAL.—A charge of electricity given to any part of a good conducting surface is instantly distributed equally over every part, and such a surface is called *equipotential*. For the momentary increase of electric energy at any point creates electric movement from higher to lower potential, which instantly results in the establishment of equilibrium at every point.

Separate points on such a surface are called *equipotential points*, and a line of such points an *equipotential line*.

LINE OF FORCE.—The direction along which electricity tends to move, from a point of higher to one of lower potential, is called a *line of force*. Such lines are perpendicular to the equipotential surfaces at the points; for, as the tendency is to move from one point to the other, it would be from one such surface to the other; and if the line differed from a perpendicular, it would imply, by the resolution of forces, that there could be two lines of force at right angles to each other, one of which would lie in an equipotential surface; implying two points at different potentials in such surface, which would be an impossibility.

SURFACE CONDENSATION.—Since the surface of a solid sphere of any good conducting material is evidently equipotential, we may regard its interior as

composed of an infinite number of such surfaces, or spherical shells, having a common center; and their radii as equipotential lines cut by such surfaces. From which it is evident that no difference of potential could exist in the interior of such a sphere.

If it were insulated, a positive charge communicated to it would evidently be distributed equally through every part, if there were no influence tending to produce a different effect. But, since the sphere would be at a higher potential than its surroundings, induction would create lines of force in the direction of the radii, which must result in the condensation of the entire charge on the surface.

Also, since every portion of the sphere is at the same potential, and since electrified bodies at the same potential repel each other, it is evident that the molecules would be self-repellent. But since they are rigid, the electricity of each molecule would repel that of every other, and move in the direction of least resistance. Let a row of molecules composing a diameter be selected, the direction of least resistance would be from the center each way. For, if surface condensation takes place (and experiment shows that it does), as the electricity of the molecules near each end of the diameter became condensed at the extreme points, its reaction being thus neutralized, more would be repelled from the center, and this would continue till all the electricity of the diameter was condensed at the ends.

But since the ends are points on the surface, and the surface is made up of an infinite number of such points, it is evident that the entire charge would be condensed on the surface.

Hence surface condensation takes place under the

influence of attraction from without and repulsion from within, in the direction of the radii.

If the charge be negative, the potential of surrounding bodies being higher than that of the sphere, electricity is, in like manner, repelled from the surface toward the center; and the negative charge takes place on the surface, as the positive charge did in the first instance. Hence the condensation is now in the interior, leaving the surface negative.

Hence surface charge, if positive, takes place under the influence of attraction from without and repulsion from within; but, if negative, under the influence of repulsion from without.

In either case the air is the dielectric between the electrified sphere and surrounding bodies: and when the charge on the sphere is positive, a negative charge of corresponding amount is induced on adjacent parts of surrounding bodies; electricity being repelled from them by the higher potential of the sphere. But when the charge on the sphere is negative, the charge on adjacent parts of surrounding bodies is positive; electricity being attracted to them by the lower potential of the sphere.

Now since surrounding bodies, as a whole, are at zero, and this positive charge, in their adjacent parts, results from the negative attraction of the sphere, it is evident that the interior potential of the sphere, as a whole, cannot rise above zero; the negative potential of its surface being exactly equal to the positive of adjacent parts of surrounding bodies, just as their negative potential was equal to the sphere's positive surface potential in the first instance. Now, since a solid of any conceivable shape could be cut from such a

sphere without altering the electrical conditions named, it is evident that, *A charge of electricity communicated to any solid conductor will be condensed on its surface.*

SURFACE TRANSMISSION.—It is also evident, that although a static charge will be thus condensed on the surface, electric transmission is not confined to the surface; since surface condensation is due to induction and repulsion, which implies the possibility of transmission through the substance to reach the surface.

Hence, although induction operates during transmission, it cannot prevent transmission through the substance: so that it must not be inferred that the conducting power is in proportion to the *surface*, but to the *mass* of the conductor.

Hence a charge of electricity which could be easily transmitted by a solid rod might be sufficient to melt a thin tube of the same diameter.

HOLLOW CONDUCTORS.—The same reasoning which applies to an electric charge on a solid sphere will also apply to one on a hollow sphere. For if any number of the spherical shells composing the interior be removed, it does not alter the equipotential of the remaining ones, nor of their radii; neither can it change the induction of the outside surroundings.

And as the form may be altered without changing these electric conditions, the same reasoning will apply to any hollow conductor.

Hence, *A static electric charge, communicated to a hollow conductor, will be condensed on its external surface.*

PROOF PLANE—But all our conclusions should be the result of experiment; to aid us in which we now require the little instrument called the *proof plane*, represented in Fig. 8; which consists of a small brass

disc, two inches in diameter, to which is attached a light ebonite handle, 12 inches long. A light, flat spring, which lies close to the disc, its lower end free, and its upper end attached to the handle, will be found convenient for attaching tin-foil in some experiments.

Fig. 8—Proof Plane.

The proof plane is used for examining the electric condition of bodies, and for transferring a small charge of definite amount. Care should be used to prevent the handle from becoming charged, which may happen from friction against the clothing or otherwise.

EXPERIMENTS WITH HOLLOW CONDUCTORS.—Let a charge of electricity be given to the insulated sphere *A*, Fig. 9, which has an opening in the top. Introduce the proof plane through this opening, taking care to prevent contact with the edges; and touch the inside surface and then the disc of the electroscope, with it. As the leaves show no divergence, it proves that the inside is not electrified.

Fig. 9—Hollow Conductor.

Now touch the outside, and then the disc, and the leaves diverge; proving that the charge is on the outside surface.

Apply the same tests to the insulated cylinder *B*, and

the same results will follow. And this cylinder may be composed either of sheet metal or wire gauze without affecting the results.

Cylinders of the latter kind are often used to protect electroscopes from the induction of electrified bodies in their vicinity.

Repeat these experiments, communicating the charge to the inside surfaces of the globe and cylinder, and the results will be the same; showing that no charge can remain on the inside.

Fig. 10—Faraday's Bag.

BAG EXPERIMENT.—To test this more thoroughly, Faraday constructed a cone-shaped linen bag, shown in Fig. 10; attached to its mouth a ring insulated on a stand, and to its apex two silk cords, by which either surface could be turned outward.

An electric charge was communicated to it, and, on testing with the proof plane and electroscope, was found to be entirely on the outer surface. The surfaces were now reversed, and the charge was found to have been reversed also, going to the outside, as before.

PAIL EXPERIMENT.—The following experiment by Faraday shows the effect of induction on a hollow conductor:

Let a tin pail *A*, Fig. 11, or any similar hollow con-

ductor, be insulated and connected by a wire with an electroscope *E*, and let an electrified metal ball *B* be lowered into it by a silk cord. The leaves will diverge as the ball enters, and the divergence increase till the ball has passed some distance below the edges: after which the divergence is not increased by its further descent.

Fig. 11—Pail Experiment.

If it be lifted out without having touched the pail, the leaves will converge, and the ball show no loss of charge: but, if allowed to touch while below the edge,

the leaves will remain divergent after its removal, but show no increase of divergence by the contact; and the ball, after removal, will be found entirely discharged.

This experiment proves:—

1. That the induction of the electrified ball has repelled electricity from the inner to the outer surface of the pail if the charge was positive, or attracted electricity from the outer to the inner surface if the charge was negative; in either case producing a divergence of the leaves.

2. It proves that induction increases as the ball descends, shown by the increasing divergence of the leaves, till all the lines of force, which can be included within the pail, are cut by its surface, after which there is no further increase of divergence.

3. It proves that there is no permanent effect if there is no contact; since the leaves converge when the ball is removed.

4. It proves that the induced charge on the pail is exactly equal to the charge on the ball, since no increase of divergence occurs from contact, although the entire charge has been communicated to the pail, as shown by the ball having lost its charge. But this can be strictly true only when all the lines of force are cut by the pail; but since some of the nearly vertical lines must escape, no matter how deep the ball descends, there must be a slight increase of divergence by contact, though it may not be perceptible.

If a charge be given to the pail and the ball be lowered into it by a wire held in the hand, the divergence of the leaves, caused by the charge on the pail, will be perceptibly reduced as the ball descends.

This proves that the inner surface of a hollow con-

ductor can be charged by induction. The charge on the pail, if positive, repels electricity from the ball, through the wire and hand, to the earth; or, if negative, attracts electricity from the earth; and in either case, a certain degree of equilibrium follows, causing a corresponding convergence of the leaves.

Entire convergence cannot be produced, since only a small portion of the lines of force from the pail are cut by the ball; while, in the former experiment, nearly all those from the ball were cut by the pail. For this reason a large ball is best for the second experiment and a small one for the first.

If the ball, in the second experiment, is lowered by a silk cord instead of a wire, there is no perceptible effect on the leaves, since induction cannot increase nor diminish the electricity of the ball when there is no earth connection.

COMBINATION OF PAILS.—The following experiment was made by Faraday with a combination of hollow conductors:—

Let four pails of different sizes be placed on an insulated support, and arranged one within the other as shown in Fig. 12: and let them be insulated from each other at bottom by cakes of paraffin, or any other good insulator, placed between them. Let silk cords be attached to the three inner ones, and the outer one be connected with an electroscope.

On lowering the charged ball into the innermost one, the leaves diverge as in the first experiment; contact between the ball and pail producing no increase of divergence, and the ball is then found to be discharged, as before; which proves that the interposition of the insulated pails, 2 and 3, has not affected the induction.

Now let pail No. 4 be lifted out by the silk cord, and the leaves will converge, and diverge again when it is replaced, showing that the charge on the ball was transferred to it.

Fig. 12—Combination of Pails.

Let a connection be now made by pieces of copper wire, let down by silk threads, between each of the pails successively, beginning with 4 and 3, till all four are in electric connection, and let the effect on the leaves be observed as each connection is made. The results will be found the same as in the first experiment,

when but one pail was used: which proves that the interposition of interior surfaces has no effect on induction; nor can it prevent the entire charge from going to the outside surface when the four pails are in electric connection; for if the three inner pails be now removed, they will be found to have lost their charge; but there will be no change in the divergence of the leaves.

This experiment is an actual demonstration of what has already been stated, that the interior of a solid conductor, or the shell of a hollow conductor, may be regarded as composed of an infinite number of equipotential shells or surfaces, from which a charge of electricity must always pass to the outside surface.

FARADAY'S HOLLOW CUBE.—A most remarkable experiment in this connection was made by Faraday with a hollow cube of wood, measuring twelve feet each way, covered with tin-foil, insulated and charged by a powerful electric machine.

He says: "I went into this cube and lived in it, using lighted candles, electrometers, and all other tests of electrical states. I could not find the least influence upon them, or indication of anything particular given by them, though all the time the outside of the cube was powerfully charged, and large sparks and brushes were darting off from every part of its outer surface."

This experiment verifies the statement made on page 12 in regard to zero potential; showing that however strong the electrification, no indications of electric action are perceptible within a space where there is perfect equilibrium. So that even if the whole earth were as powerfully charged, in proportion to its size, as Faraday's cube, we, who live on it, could perceive no electric action, if the charge were as uniform as on the cube.

But if it be objected that the case is not parallel, seeing that we live on the surface, it must be remembered that we have an atmosphere above us which is a part of the earth's matter; so that, although we live on the *solid* surface, we do not live on the *outer* surface: and the surface on which we live is practically equipotential over limited areas.

Faraday, evidently, might have generated electricity with insulated instruments, inside the cube, and condensed it on insulated conductors, without either disturbing the electric conditions by which he was surrounded, or being prevented by them: just as we do without disturbing the earth's electricity, or being prevented by it. But any connection by a conductor, between his instruments and the cube, would have caused the charge to disappear; just as a similar connection with the earth produces the same result.

THICKNESS OF ELECTRIFIED SURFACE.—The idea of surface condensation implies that an electrified surface must be something more than a mere superficies. It must have a certain degree of thickness, the electricity penetrating the conductor and surrounding air to a certain depth, in proportion to the resistance of the air, and the attraction or repulsion of the charge on the conductor. Hence the amount of static charge which may be condensed on a conductor, per unit of surface, depends on the resistance of the air.

CONVECTION.—It has already been shown that dry air is one of the best insulators; but, since it is a fluid, its resistance cannot be so great as that of a solid of the same insulating power; for the air molecules, in contact with an electrified surface, becoming charged, fly off under the influence of repulsion and induction, while

those farther out rush in to take their place; creating air currents around the conductor, by which its electricity is gradually dissipated. The removal of electricity by the air in this way is called *convection*.

VARIATION OF CHARGE.—Since the insulating power of the air varies greatly with its humidity and temperature, and since its electric potential is also variable, the charge which may be condensed on a conductor will vary in like proportion; dry, cold air being much more favorable to the condensation of a high charge than damp, warm air; and air at a high electric potential than air at a low potential.

Analogous to this is the influence of atmospheric pressure on steam; the temperature varying with the pressure under which it is generated. Here *pressure* constitutes resistance, while in the case under consideration the resistance is due to the causes mentioned.

Equal electric condensation on every part of the surface is never practically true; as the induction of surroundings varies, and form, as will be shown hereafter, has an important influence. It could only be true of an insulated sphere, surrounded by a homogeneous medium, and removed from all other influences.

INFLUENCE OF FORM.—It has already been stated that form exercises an important influence on the amount of static charge which may be condensed on a conductor; and that a charge on an insulated sphere is equally distributed over its surface, when the surrounding induction is equal: also that the air, by its insulation, retains this charge on the surface, and by its convection gradually removes it. It is evident also that these forces act at equal distances from the center.

ELECTRIFIED SPHERES.—Let two insulated metal spheres, of equal size and similarly charged, be placed in contact, as represented in Fig. 13. It is evident that either of them, separately, would fulfill the conditions

Fig. 13—Spheres in Contact.

just named; but when placed in contact, they must be regarded as one mass, having its center at the point of contact; the electric distribution being the same on each.

Hence the forces of induction and repulsion which before acted to remove electricity from the center of the single sphere to the parts most remote from it—that is, to the surface—now act in the same manner, to remove electricity from this new center to those parts of the mass most remote, that is, to the points *A* and *B*, and the surfaces surrounding them.

There must also be a certain amount of electricity distributed over the entire surface of each sphere; and there must be repulsion between the surfaces adjacent to the point of contact: so that the charge will be zero at this point, and increase each way toward *A* and *B*.

This may be demonstrated by touching the points *A*, *B*, and *C* with the proof plane, and, after each contact, bringing it near the disc of the electroscope; taking care to discharge it with the finger before making the next test.

It will be found that the central point shows scarcely a trace of electricity, while the points *A* and *B* are

strongly electrified. The same test, applied to intermediate points, shows the charge on them to be in proportion to their distance from the central point.

ELECTRIFIED CYLINDER.—Instead of the two spheres, we may substitute an insulated metal cylinder, with hemispherical ends, provided with pith-ball electroscopes at the ends and center, as represented in Fig. 14.

A light charge of electricity on the cylinder will cause the balls at the ends to diverge in opposite directions, while the central ball will remain unmoved, or but slightly affected; showing that the principal part of the charge is condensed on the ends, and that induction and repulsion are operating to remove electricity to the points

Fig. 14—Electrified Cylinder.

farthest from the center, as shown by the position of the balls at the ends.

If a sphere be made to oscillate near one of the balls, at right angles to the length of the cylinder, the effect of induction will be shown by the ball following the movement of the sphere.

INFLUENCE OF POINTS.—If a cylinder having cone-shaped ends be substituted for the one with hemispherical ends, dissipation of the charge, instead of condensation, will occur. For, on the hemispherical ends, the charge is retained by the resistance of the air on the surface; but the cone-shaped ends terminate in points which have no surface, hence there can be no resistance.

But if resistance is removed, even from a single point, it is evident that the entire charge must pass off through

that point; since the removal of electricity from any point on a surface creates a difference of potential between that and surrounding points, producing an electric movement in the direction of the point of no resistance, which must extend to every part of the surface, and continue till equilibrium is restored.

Instead of the cylinder with cone-shaped ends, we may use one with needles attached to the ends, as represented in Fig. 15. A wooden cylinder covered with tin-foil can easily be changed in this way.

Fig. 15—Cylinder with Points Attached.

It will be impossible to charge such a cylinder, even if only a single needle be attached to any part of the surface. A projecting angle on any part of a conductor will tend to produce the same result.

Effects somewhat analogous to these may be obtained by dipping into water a spherical body, and also a sharp-pointed spike having the same amount of surface. On lifting out the spherical body, water will adhere to it, and collect in a large drop at the lowest part; being held there by adhesion and atmospheric pressure. But if the spike be lifted out, point downwards, the water will drop off when it reaches the lowest point, there being no surface there on which it can be retained by those forces.

ELECTRIFIED SPHEROID.—If a metal sphere be flattened at the poles till it assumes the form of an oblate spheroid, as shown at *A*, Fig. 16, the face of a cross-

section through the poles, as shown at *B*, will have the same form as a cylinder with hemispherical ends. And since it has been shown that a charge of electricity on such a cylinder is condensed on the ends, it is evident that a charge on such a spheroid will, in like manner, be condensed on its outer edge.

ELECTRIFIED DISC. — If a flat metal disc, with a thin edge, be electrified, the charge will go to the outer edge, as in the last case. But resistance, being in proportion to surface, is very small on such an edge, and the charge is rapidly dissipated. Hence such a

Fig. 17—Electrified Disc.

disc, when constructed for the purpose of condensing electricity on it, should be provided with a round rim, which may be called a *resistance rim*.

If it be insulated, and there be placed on its opposite sides, near the edge, two little metal stands with pointed stems, on which are balanced light metal pointers, having arms of unequal length, as shown in Fig.

Fig. 16—Electrified Spheroid.

CHAPTER VI.

ACCUMULATORS.

THE CHARGED PANE.—The electric charge which may be condensed on the surface of an insulated conductor is comparatively small, when such a conductor is remote from inductive influence.

But when another conductor, having a connection with the earth, is placed in its immediate vicinity, the charge may be greatly increased.

To prove this, let a sheet of good insulating glass,

Fig. 18—The Charged Pane.

varnished with shellac, be coated on opposite sides with tin-foil, to within about two inches of its edge, and placed on an insulating support, as shown in Fig. 18. A small charge can be given to the tin-foil, on the upper surface,

which will be indicated by sparks passing between it and the body from which the charge is given. But the limit is soon reached, and no more sparks will pass.

Now let the lower surface be connected with the earth by a strip of tin-foil, and sparks will again pass freely between the charging body and the upper surface, till a charge greatly in excess of the former is given.

If the tin-foil strip be suspended with its lower end near a conductor, as shown, sparks will pass between

it and the conductor, simultaneously with the sparks on the upper surface; indicating that each surface receives the same amount of charge.

But the potential on opposite surfaces will be opposite. If the upper surface acquires positive potential, by an increase of electricity, the same amount will be repelled from the lower surface, making it negative. But if the upper becomes negative by a decrease, electricity, to the same amount, will be attracted to the lower surface, making it positive.

To prove that these charges are equal, let the tin-foil strip be removed after the plate has been charged; and a wire, held by a piece of india-rubber tube, to insulate it, be bent so that its ends come into contact with the opposite surfaces, as shown in Fig. 19: a flash and report will follow, and both surfaces, after the wire has remained in contact for a few moments, will be found completely discharged.

Fig. 19—The Pane Discharged.

Now, since the removal of the strip produced complete insulation, perfect equilibrium could occur only by the positive of one surface being exactly equal to the negative of the other.

Since induction varies inversely as the square of the distance (page 47), it is evident that, if this factor alone is considered, the amount of charge which can be given will be in the inverse ratio of the thickness of the glass, and hence greater on thin than on thick

glass. But since the resistance of glass is in the direct ratio of its thickness, when the specific inductive capacity is the same, this factor also must be considered.

Hence, in the construction of instruments involving these principles, if great sensitiveness and a low potential is desired, the glass, or other dielectric, should be thin : but if the highest attainable potential is desired, there should be sufficient thickness to resist fracture or puncture.

The uncoated margin must also be wide enough to make the resistance there equal to that of the thickness ; a small fraction of an inch in thickness having a resistance equal to that of several inches of surface.

No definite rules can be given, as the resistance of various kinds of glass, and other dielectrics, varies greatly, as well as the cases in which they may be required.

As the positive and negative on opposite surfaces are equal, it is impossible for a change of potential to occur on either surface without a corresponding change on the opposite surface. Hence a conductor brought into contact with either surface alone will not change its potential, unless directly or indirectly connected with the opposite surface. Hence the charge on each surface is said to be *bound* by the opposite charge.

The convection and conduction of the air, so far as it can act equally on both surfaces, will in time restore equilibrium. It may also be restored by the oscillation of a solid body, as a pith ball, suspended between conductors connected with both surfaces ; or, by direct connection through a conductor, as already explained.

Instruments constructed for accumulating electricity in this way are called *accumulators*, or *condensers*.

THE LEYDEN JAR.—The first discovery of an accumulator was made by Kleist, a clergyman of Cammin, in Pommerania, who stated in a letter to Dr. Lieberkühn, of Berlin, Nov. 4, 1745, that by pouring a little mercury, “spirits,” or water, into a phial and connecting it with a nail through the cork, he could electrify it through the nail, ignite “spirits of wine” with it, and receive a shock by touching the nail with his finger.

The same discovery was made in the following year in Leyden, by Cuneus, a pupil of Musschenbroek, who electrified some water in a flask, which he held in his hand, by bringing it into contact with a chain from the conductor of an electric machine. On attempting to remove the chain with his other hand, he received an electric shock which so frightened him that he dropped the flask. Musschenbroek, having tried the experiment, said he would not take a second shock for the crown of France.

The discovery created great excitement, and led to the construction of improved instruments, to which the name “Leyden jar” was given.

The water in this instance constituted the inside coating, the hand the outside coating; and, when the other hand touched the chain, both surfaces were connected by a conductor, and a discharge followed, which produced the shock.

Fig. 20 represents the Leyden jar as it is usually constructed. The essential elements are two conducting surfaces separated by a dielectric; but, for convenience in charging and discharging, a wooden cap is fitted to it, through which passes a brass rod, terminating in a ball above, and to its lower end is attached a

light spring, or a chain, which comes into contact with the inside coating.

Tin-foil is the usual coating, and is put on with paste, covering both surfaces equally to within about three inches of the top. Light sheet brass makes a more substantial outside coating, and does not require at-

Fig. 20—Leyden Jar and Discharger.

tachment to the surface. It can also be used for the inside coating, when the mouth is the full width of the jar and the sides are straight. Sulphuric acid is also sometimes used for the inside coating of jars designed for special purposes.

An instrument called a *discharger* is also represented at *A*, in Fig. 20. It consists of a curved brass rod, terminating in balls, and having an insulating handle, of ebonite or glass, attached to its center. It

is sometimes jointed at the center, and furnished with two handles, as represented at *B*, Fig. 20. Its use is the same as that of the bent wire already described.

The Leyden jar can be made of any insulating material capable of being molded into the proper form; but glass seems to be the only substance capable of resisting the enormous strain to which the dielectric is subjected under a full charge.

Glass suitable for the purpose must be free from any substance which makes it a partial conductor. Hence such glass as is commonly used for fruit jars, candy jars, and druggist's bottles cannot be used, since it contains metallic substances.

Glass of a bright green color, free from bluish tint, also the kind known as "hard flint," makes the best Leyden jars.

The Leyden jar is charged by an electric machine; its inner coating being connected with the machine, and its outer coating with the earth, or with the opposite electrode of the machine; though it is not material which coating is connected with the machine, except as a matter of convenience. The jar may be insulated, and the charge given to the outer coating, if the inner coating is connected with the earth.

It is also immaterial whether the charge given is positive or negative, as the opposite charge will always be induced on the opposite surface; electricity being repelled to the earth when a positive charge is given, or attracted from the earth when negative is given.

The *electromotive force* (E. M. F.) of a jar is equal to the difference of potential between its inner and outer coatings.

CHARGE BY CASCADE.—The method of charge by cascade, first proposed by Franklin, is as follows: Let a number of jars of equal size, as *A*, *B*, *C*, *D*, be arranged as represented in Fig. 21; the outer coating of each, commencing with *A*, being connected with the inner coating of the one next to it; *D* having its outer coating connected with the earth, and *A* having its inner coating connected with the machine. And let *A*,

B, and *C* be well insulated on cakes of paraffin or some equally good insulator.

A positive charge given to the inner coating of *A* will induce negative on its outer coating, by repelling the same amount of electricity; and this repelled charge must go to the inside of *B*, since it has no other outlet. Hence the inner coating of *B* will be positively charged, and electricity will, in like manner, be repelled from its outer coating to the inner of *C*. Hence the charge of each jar in the series will be similar to that of *A*; electricity from the outer coating of *D* being repelled to the earth.

Fig. 21—Jars in Cascade.

As the energy expended is distributed among four jars, it is evident that the charge of each must be much less than if the same amount had been expended in charging one jar: since the energy accumulated cannot exceed the energy expended. But, as the charge is in the inverse ratio of the thickness of the glass, the resistance from this source must increase from *A* to *D*, in proportion to the number of thicknesses interposed: and the charge must vary in the same ratio; the negative being greatest on the outer coating of *A*, where only one thickness is interposed, and least on the outer coating of *D*, where four thicknesses are interposed;

the positive on the inner coatings varying in the same ratio. The same variation must also occur in the resistance of the connectors, and produce a similar effect, in a limited degree; the resistance of a conductor being directly as its length.

If the charge given to the inner coating of *A* be negative, the electric movement is reversed; all the inner coatings becoming negative, and the outer positive; electricity being attracted from the earth to the outer coating of *D*.

The insulations and connections should receive careful attention, so as to prevent loss by leakage; which will inevitably occur if the insulation is imperfect, or if the connectors have points, sharp edges, or projecting corners.

After the charge is given, the jars should be separated, placed in connection with the earth, and each discharged separately. A single jar, charged to the same amount, should then be discharged, and the results compared.

This method will indicate, roughly, the amount of charge of each jar; but the electrometer, to be described hereafter, will give more accurate results.

THE LEYDEN BATTERY.—When a number of jars have their inner coatings joined by conductors, and also their outer coatings in like manner, the combination is called a Leyden battery.

A convenient form of such a battery is represented by Fig. 22, in which connectors between the inner coating radiate from a central jar. The outer coatings are made of sheet brass, nickel-plated, and screwed to a wooden base, their connections being made with copper wires attached to the points of the screws underneath.

This construction for the outer coatings makes them durable, gives the jars a firm attachment, and adds greatly to the neatness and beauty of the instrument.

The E. M. F. of a Leyden battery is the same as that of a single jar having the same amount of coated surface. There can be no increase of intensity from any special arrangement of the jars, as such a battery is merely an *accumulator*, and not a *generator* of electric-

Fig. 22—Leyden Battery.

ity. But when great E. M. F. is required it is generally more convenient to use a battery than a single jar of equal energy. And, in case of fracture from an overcharge, a small jar can be replaced at less expense than a larger one.

In charging or discharging a battery, it is immaterial which jar is selected: for all the inner coatings being connected together, as well as all the outer coatings, each is practically the same as a single coating of equal

size; and connection with any part of either coating affects the whole of that coating.

DISCHARGE THROUGH A BOOK.—The discharge from a Leyden jar or battery, passed through a card or a thin book, leaves a puncture, with *a burr projecting from each surface*.

Fig. 23—Discharge Through a Book.

To perform this experiment successfully, let one knob of the discharger be placed in contact with the outer coating, and the other in contact with the book; and let the book, held by its edge, with the knob against it, be brought quickly into contact with the knob of the jar, and the discharge will take place as shown in Fig. 23.

In this way a book of one hundred or more pages may be perforated.

If the book is first placed in contact with the knob of the jar, part of the charge will escape from the edges and corners of the leaves, and the experiment is liable to fail.

The burr projecting from each surface, after the discharge through a book or card, has been relied on as a proof of the dual nature of electricity, and ascribed to the rush of positive and negative in opposite directions. It is also attributed to the expansive force of heat, or of gas, generated by the discharge.

The first theory cannot be accepted, unless we have stronger proof of the dual nature of electricity than is afforded by this experiment. And the second also fails; since in the case of a discharge through a book, the leaves may be held so loosely as to allow a free outlet for expansion from heat or gas, and yet the burr turns in opposite directions from a point near the center of the book, and becomes more prominent when the leaves are thus held than when they are compressed; whereas, if the burr were due to the expansive force of confined heat or gas, the reverse would be true.

Since these theories are unsatisfactory, let us endeavor to explain this phenomenon in accordance with the principles which we have been considering.

Let a jar be charged on its inner coating, and discharged through a book, as represented in Fig. 23. Suppose the charge to be positive, electric movement being from higher to lower potential, it would be from the knob of the jar to the nearest knob of the discharger. The entire charge of the inner coating, passing out through the knob, would induce a high

negative potential on that point, on the nearest surface of the book, in a line between the knobs; repelling the electricity of the book along that line to the opposite surface, which would thus become highly positive.

The paper being a very imperfect conductor, the charges thus induced do not spread rapidly, but remain concentrated for a moment on small circular spaces around each of these points; the greatest intensity being at the centers. Hence there is a powerful attraction between the knob of the jar and this negative point on the surface of the book; and also between the knob of the discharger and the positive point on the other surface; under the influence of which the paper on each surface gives way and bursts outward toward the knobs; that surface next the knob of the jar being attracted, and that next the knob of the discharger repelled.

As each outward leaf bursts, the next, becoming then the outer one, bursts also, till the perforation is complete from the center each way. All of which occurs instantaneously.

Meantime the electricity from the knob of the jar follows up this inductive effect on the electricity of the book; but meeting great resistance from the imperfectly conducting paper, and the air between the leaves, it is concentrated on each leaf successively; so that the inductive force is constantly in advance of the charge, the leaves and layers of air between them constituting the dielectric.

It will be noticed, then, that this is not a case of energy going through a passive medium, but of *energy acting on the energy of that medium, causing it to become active and perform work.*

It should also be noticed that when the leaves are held loosely, the thickness of the air dielectric is increased; each layer of air having a charged surface of partly conducting paper on each side of it, is in the position of the coated pane, a powerful attraction between the surfaces acting across it. And when the paper bursts there is more room for the formation of a burr, and less resistance to the tearing of the paper, which accounts for the increased prominence of the burr.

If the charge of the jar is negative, the same results occur in reverse order.

THE RESIDUAL CHARGE.—When a Leyden jar is discharged, there still remains a slight difference of potential between the coatings, which is known as the *residual charge*. Hence, a small discharge can be obtained a moment after the first; and this also leaves a residual, bearing about the same proportion to the second discharge as the second to the first, when the same length of time elapses between them. A number of successive discharges may thus be obtained, which constantly decrease in amount till no further discharge is perceptible. But, even then, it is not probable that perfect equilibrium is restored.

To understand this, we must remember that even the best dielectric is a partial conductor: and that while electric movement is instantaneous in a good conductor, it is very slow in a non-conductor. In the Leyden jar we have a combination of both—two conductors separated by a non-conductor. And, when the charge is given, every part of each coating instantly becomes electrified, one coating positively and the other negatively, on the surfaces next the glass.

The electricity, on the positively electrified coating, slowly penetrates into the glass, acting inductively on its electricity, which it repels from the opposite surface; and producing, probably, a temporary strain or distortion of its structure.

When the first discharge takes place, there is a relief from this strain; and, as the electrified glass slowly returns to its former state, the electricity which had penetrated it returns to the conducting surface.

This view receives confirmation from the fact that delay increases the residual charge, giving time for the electricity to come out of the glass and accumulate: while it has the opposite effect on the primary charge, reducing it by giving time for dissipation.

Tapping the jar lightly hastens the increase of the residual charge, the vibratory motion thus given to the glass tending, probably, to relieve the electric strain.

JAR WITH MOVABLE COATINGS.—If a Leyden jar be constructed with any rigid metal, as sheet brass, for both coatings, as suggested on page 76, and the conducting rod be attached to the inner coating, the coatings may be removed and replaced at pleasure, as represented in Fig. 24: and we have the means of investigating certain phenomena in regard to the electrification of the different parts.

Let a charge be given to such a jar, and the coatings removed carefully, so that they shall not be connected by a conductor during removal: they may now be brought into contact without producing any electric effect; and the jar also may be handled with a like

Fig. 24—Jar with Movable Coatings.

result : but, on replacing the coatings, a full discharge can be obtained, the same as if they had not been removed.

But if, while the coatings are removed, the jar be examined by touching both surfaces with the finger and thumb, or a small discharger, made with a bent wire, at any point below a line marking the position of the upper edges of the coatings, a discharge can be obtained from that point. In this way a number of small discharges can be had from various points, but no general discharge.

This proves that *the charge remains on the glass, while the coatings are removed* ; but that the resistance of the glass prevents a general discharge. But it cannot be accepted as proof that the charge is confined to the glass, when the coatings are in contact with it ; unless it can be shown that the charge remains on the glass after the removal of both coatings at precisely the same instant ; which could not be done with the care necessary for so delicate an experiment. But when the coatings are removed separately, the charge must be transferred to the glass during the removal of each : since it is impossible to produce any change of potential on either surface, unless a corresponding change is produced, at the same instant, on the opposite surface ; each being bound by the opposite.

VARIOUS EFFECTS OF THE DISCHARGE.—The discharge of a Leyden jar of moderate size is sufficient to explode gunpowder, and to ignite various substances ; as phosphorus, powdered resin, sulphuric ether, and alcohol ; while that of a large Leyden battery fuses wires, magnetizes steel, and destroys animal life.

With a battery of 550 square feet of coated surface, large steel bars have been magnetized, iron wires, $1\frac{1}{16}$

of an inch in diameter, and 25 feet long, melted into globules; and tin wires, $\frac{1}{8}$ of an inch in diameter, and 8 inches long, dissipated in smoke.

Tyndall accidentally received a charge from a Leyden battery of "fifteen large jars" during a lecture, and describes his experience as follows: "For a sensible interval life was absolutely blotted out, but there was no trace of pain. After a little time consciousness returned; I saw confusedly both the audience and the apparatus. But though the *intellectual* consciousness of my position returned with exceeding rapidity, it was not so with the *optical* consciousness. For my body presented to my eyes the appearance of a number of separate pieces. The arms, for example, were detached from the trunk and suspended in the air. In fact, memory and the power of reasoning appeared to be complete long before the restoration of the optic nerve to healthy action."

Gunpowder cannot be exploded by the ordinary discharge; the only effect of which is to scatter it. But when the discharge is retarded, by introducing into the circuit an imperfect conductor, as a wet string, it explodes readily. By this method also gun-cotton, phosphorus, and other highly inflammable substances may be ignited.

For such experiments the *universal discharger*, represented by Fig. 25, is convenient. It is constructed with a base, in the center of which, mounted on a stem, is a small circular tablet of some insulating material, as ebonite; and at each end, mounted on insulating stems, are brass sliding rods, each terminating in balls, and passing through a socket hinged on the top of its stem. A plaster of paris receptacle, to hold inflammable substances, should also be provided.

The substance to be operated on is placed in the receptacle on the tablet, the inner terminals of the sliding rods adjusted on opposite sides of it, and the outer terminal of one rod connected with the outer coating of the jar or battery; and the circuit completed by connecting the outer terminal of the other rod with the knob of the jar or battery, by the discharger, as shown.

The wet string, or other imperfect conductor, when

Fig. 25—Universal Discharger.

used, can be introduced into any convenient part of the circuit, as at *S*.

SPONTANEOUS DISCHARGE.—A spontaneous discharge is liable to occur in attempting to charge a jar beyond its capacity: and, if the

glass is thin at any point, it may be fractured in this way; but if the resistance of the insulating margin is less than that of the glass, the discharge will take place over that surface, without injury to the jar, electricity always following the path of least resistance, whether longer or shorter.

DISRUPTIVE DISCHARGE.—When a discharge takes place through the air or any other dielectric, it is termed *disruptive*; since the electricity must force a passage and break down opposing barriers. Such a discharge is always accompanied with light, heat, and sound; as expressed by the terms *spark* and *snap*, *flash* and *report*—effects due to the resistance encountered, and not qualities inherent in electricity.

SILENT DISCHARGE.—But when the discharge takes place through a good conductor of sufficient size, it is termed *silent*; since light and sound are absent; the resistance encountered being only sufficient to produce a slight amount of heat.

The discharge through a point is also termed silent; since a point, as already shown, offers no resistance; and hence there is little or no sound, even when the discharge passes through intervening air. A battery discharge, sufficient to destroy life, may be received with impunity through the point of a cambric needle, held in the hand, without producing any unpleasant sensation.

LICHTENBERG'S FIGURES.—If, on a plate of ebonite, or of glass varnished with shellac, figures be traced with the knob of a positively charged Leyden jar, and sulphur dusted over the surface, inclining the plate and tapping it to remove the surplus; the sulphur will adhere to the lines traced, spreading out in a beautiful fringe, as shown in Fig. 26, which is from a photograph of a figure made in this way.

A similar result can be obtained by tracing lines with the outside of this jar, or with the knob of a negatively charged jar, and dusting the surface with red lead.

Or a mixture of sulphur and red lead may be used, and separate figures traced; the jar being charged positively for one figure, and negatively for the other. The sulphur, it is claimed, adheres to the positive, and the lead to the negative lines. Any non-conducting surface may be used, also various other powdered substances.

It should be noticed that the loss of charge, whether positive or negative, from the inner coating, while tracing

the figures with the knob, is balanced by an equal loss from the outer coating through the hand in which the jar is held. Hence, when the tracing is made with the outer coating, the knob must be held in the hand, to produce the same effect on the inner coating: the jar being first placed on an insulator to prevent a discharge and consequent shock, by indirect connection through the earth.

Fig. 26—Lichtenberg's Figures.

An inspection of the figure shows, that at the point where it begins above, the fringe lines radiate from a common center; but that, as the curve is produced from right to left downward and from left to right upward, they point diagonally in the direction in which the knob of the jar moves. The explanation is as follows:—The

surface being a non-conductor, the electricity has to force its way against strong resistance, bursting through at the points where resistance is least, and forming the fringe. The strongest effect is produced where the knob first approaches the surface; as the jar has then a full charge: and the first action is a disruptive discharge through the air, producing the circular, star-like figure, at that point. But as the knob moves along the surface, after contact, new lines start out at right angles to the line of movement. And as the knob leaves a point where such a line has started, it exerts an inductive action on the original impulse, which tends to turn this line forward; the diagonal direction being the resultant of these two forces acting at right angles to each other. And the forked branches are the result of similar inductive action of the main fringe lines on the branch lines.

We have, in this experiment, a graphic demonstration of the effect of an insulating surface in resisting electric movement: since the figures show the exact location of the electric force; which, we see, is confined chiefly to the tracings, spreading only to the limited extent represented by the fringes.

It also shows that the effects produced in different substances, by opposite electric influences, are dependent on the electric condition of the substances themselves: so that a mixture or a compound may, in this way, be separated into its elements. The sulphur in this experiment becoming negative, as claimed, by friction, is attracted to the positively charged lines, while the red lead, becoming positive, is attracted to those negatively charged. This principle has numerous useful applications in the arts.

CHAPTER VII.

ELECTRIC GENERATORS.

THE ELECTROPHORUS AND FRICTIONAL MACHINE.

THE only electric generators noticed thus far are the rods of glass, ebonite, and sealing-wax; rubbed with silk, woolen, or fur: but it is evident, that for such work as the charging of Leyden jars and batteries, and similar experiments, we require generators of far greater capacity. But it was thought best to anticipate their existence, and defer their introduction till there had been a full consideration of the principles on which the

Fig. 27—Electrophorus.

various kinds depend: so that they might all be included in one comprehensive view; from which the merits of each, and the principles of

its construction could be more fully ascertained.

THE ELECTROPHORUS.—This instrument, invented by Volta, is one of the simplest forms of a static generator; but it is of great utility in furnishing an unfailing, though limited supply of electricity, for numerous delicate experiments.

The following style, designed by the author, and represented by Fig. 27, makes a handsome, convenient, and very efficient instrument.

On a wooden base thirteen inches square, constructed of layers glued together to prevent warping, is placed a thin sheet of brass of the same size; over which is placed a sheet of ebonite of equal size, $\frac{1}{16}$ of an inch thick; and both attached to the base by screws near the corners.

On the ebonite is placed a circular plate or cover, made of No. 20 sheet brass, twelve inches in diameter, perfectly flat, and having a round resistance rim joined to the upper surface. In its center is an ebonite handle, seven inches high; and from its rim projects a goose-neck, made of No. 8 brass rod, terminating in a half-inch brass ball; near which, on the edge of the base, is a brass strip, $\frac{5}{8}$ of an inch wide, connected with the lower plate.

The base may be made of metal, if preferred, in which case the lower plate and strip are unnecessary, the base itself taking the place of the plate.

In this instrument we have two conductors separated by a dielectric; the upper one insulated, and the lower connected with the earth.

The cover being removed, the dielectric is beaten briskly with a piece of catskin, or other fur, by which its upper surface is electrified; and the cover is then replaced.

Suppose the charge to be negative; electricity having been removed by the fur, the same amount is attracted from the earth to the under surface of the dielectric, and to the upper surface of the brass plate in connection with it; which thus become positive by induction. The under surface of the cover also becomes positive and its upper surface negative.

Let a connection now be made between the lower

plate and cover, by touching the strip and knob with the finger and thumb, or a small discharger; the electricity accumulated on the lower plate will pass to the cover, producing a shock if passed through the hand.

The cover thus becomes positive; but its charge is neutralized, or bound, by the negative of the dielectric. Let it be lifted off by the insulating handle; its charge being no longer bound, a discharge, producing a spark,

an inch or more in length, takes place, when the knuckle or any conductor is presented to the knob, as shown in Fig. 28.

Fig. 28—Discharge of Electrophorus.

The removal of the cover with its positive charge, having left the upper surface of the dielectric negative, a positive charge is again attracted to the under sur-

face and plate, as before; and the cover, having been discharged and replaced, the process may be repeated with the same results an indefinite number of times, and Leyden jars charged, or other electric work performed.

Suppose the original charge to be positive, the same results occur in reverse order. Electricity having been imparted by the fur to the upper surface of the dielectric, the same amount is repelled from the under

surface and plate, making them negative. The under surface of the cover also becomes negative and its upper surface positive. Connection being made as before, electricity passes from the cover to the lower plate; leaving the cover negative, and its charge bound by the positive on the upper surface of the dielectric.

The cover being removed, and a conductor presented to the knob, a discharge takes place; electricity now passing from the conductor to the cover, instead of from the cover to the conductor as before.

The removal of the cover, with its negative charge, having left the upper surface of the dielectric positive, electricity is again repelled from the under surface and plate by induction: and the cover having been restored to zero and replaced, the process may be repeated as before.

We see, then, that when the charge is negative, electricity is attracted from the earth to the lower plate, then passes to the cover, and then from the cover to the presented conductor; but when the charge is positive, electricity is repelled to the earth from the lower plate; then an equal amount passes from the cover to the lower plate, and the same amount passes to the cover from the presented conductor.

Hence, when the instrument *receives* a positive charge, it *gives* a negative charge; and when it *receives* a negative charge, it *gives* a positive charge.

It will also be noticed that the initial charge is given by friction, but all subsequent charges are obtained by induction.

If the cover be removed, without first making connection between it and the lower plate, no charge will be found on it; since it has neither gained nor lost

electricity through any external source; and its own electricity, being merely changed to the upper or lower surface, by the positive or negative of the dielectric, is restored to zero when removed from that influence.

This connection may be made automatically, by placing a short brass pin in a hole made through the dielectric, its upper end even with the upper surface, so that it shall touch the cover and also the lower plate. This makes the instrument more convenient for obtaining charges in rapid succession: but, when used to demonstrate the principles involved in its construction, as above, the pin should be removed.

The top of the handle should be grasped, when removing the cover, to prevent a partial discharge through the hand.

The electrophorus will retain its charge for months; and, like the Leyden jar with movable coatings, can be taken apart and put together again without perceptible loss of charge; but, when not in use, the charge is gradually dissipated, so that only a residual remains. Hence it should be charged again before immediate use, if great efficiency is desired. This property of constancy probably suggests the name, electrophorus, electricity-bearer, from *φερω* to bear, *ηλεκτρον* electricity.

THE FRICTIONAL MACHINE.—The principle of this machine is the same as that of the rod and rubber. It was invented by Otto Guericke, and consisted, at first, of a globe of sulphur, revolved on an axis by a crank, the hand being used as a rubber. Subsequently a globe of glass was substituted for the sulphur; but as insulation was disregarded in both styles, only feeble results were obtained, and the machines fell into disuse.

Boze, of Wittenberg, revived and improved them,

using the glass globe, and a band wheel and belt to increase their speed; and collecting the electricity on an iron tube, suspended by silk cords, from which hung a chain in contact with the globe.

Further improvement was made by the use of a leather rubber stuffed with hair: and subsequently the globe was replaced by a glass cylinder, on one side of

Fig. 29—Plate Electrical Machine.

which the rubber was mounted on a glass pillar; and, on the other side, similarly mounted, was a brass cylinder, called the *prime conductor*, from which a row of points projected toward the glass. An oil silk flap enveloped the upper part of the glass cylinder; and a chain was used to connect either the rubber or the prime conductor with the earth, as desired.

The plate machine, invented about 1787, was con-

structed on the same principles, a glass plate being substituted for the glass cylinder, and has now come into general use. Fig. 29 represents one of the prevailing styles.

It consists of a disc of plate-glass *A*, mounted on a wooden base with wooden or glass pillars, and revolved by a crank with an insulated handle. A pair of rubbers *B*, made of soft leather or felt, are pressed against the glass on opposite sides by a pair of brass springs *C*, the pressure being adjusted by a screw. These are mounted on a glass pillar, and connected above with a brass ball; and a brass chain, which may be removed, connects them with the earth.

Mounted on a glass pillar is the prime conductor *D*, made of brass, and consisting of a pair of balls, from the lower one of which projects a pair of combs, which extend on opposite sides of the glass, and whose teeth come within a quarter of an inch of it. And, from the opposite side of the same ball extends a rod, terminating in a small ball.

A silk cover envelops the lower part of the glass plate, and the rubbers, on the surfaces in contact with the glass, are coated with an amalgam, composed of five parts zinc, three parts tin, and nine parts mercury, melted together, pulverized, and made into a paste with lard.

The machine should be dry and warm before use, as moisture condenses on the surface of the glass when it is colder than the atmosphere, and suspends insulation. For this reason ebonite pillars have an advantage over glass, being less liable to condense moisture.

Ebonite has also been used for the plate, but is not so reliable as glass; and its liability to warp with heat, when in thin plates, makes it very objectionable.

ITS MODE OF ACTION.—The plate being revolved in the direction of the arrow, electricity is generated by the friction of the rubbers; the charged surface of the glass passing directly into the silk cover, which prevents loss of charge from contact with the air.

If the charge on the glass is positive, when the charged surface comes opposite the combs, electricity passes through them from the plate to the prime conductor, where it accumulates. The glass, being thus discharged, passes round again to the rubbers, which, having become negative from parting with electricity to the glass, have received electricity from the earth through the chain.

Each portion of the plate is thus alternately charged and discharged, as it passes first to the rubbers, and then to the combs; the lower half being constantly positive, and the upper half at zero, except the residual; electricity passing to the rubbers from the earth, and being carried round by the plate to the prime conductor.

If the charge on the plate is negative, the transfer takes place in reverse order; electricity passing from the prime conductor to the plate, from the plate to the rubbers, and from the rubbers to the earth; the prime conductor becoming negative and the rubbers positive.

If the prime conductor be placed in connection with the earth, by having the chain transferred to it, the charge, whether positive or negative, will take place on the ball and other parts connected with the rubbers.

If the prime conductor and rubber be connected by the chain, no charge can occur on either; since electricity constantly passes from one to the other through the chain, as it is generated.

If the chain be removed entirely, only a very limited charge can occur, derived from the material of the machine itself.

The limit of the charge is reached when its potential energy, whether positive or negative, so far exceeds the resistance of the air, that the loss of charge by convection, as explained on page 66, shall equal the energy generated. When the atmosphere is damp, or its electric potential low, this limit is soon reached; but when dry, and at a high electric potential, a much greater charge can take place.

MACHINE DESCRIBED BY NOAD.—The largest machine of this kind of which we have any record was made some years ago for the Panopticon of Science in London. According to Noad, it had a plate ten feet in diameter, three pairs of rubbers, each three feet in length, and a pear-shaped prime conductor, six feet in length, and four feet in diameter at its widest part.

It was operated by steam power, and gave sparks fifteen to eighteen inches in length; and charged to its full capacity, in less than a minute, a Leyden battery of thirty-six jars, having one hundred and eight square feet of coated surface.

MEASUREMENT OF ENERGY.—The amount of electricity which a well-constructed machine can generate is in proportion to the surface area of the plate, which may be increased to any practicable limit, the other parts being increased in like proportion. It is roughly estimated by the number of sparks of a given length and energy which can be obtained in a given time, when an uninsulated conductor is brought near the prime conductor; or by the length of time required to

charge a Leyden jar or battery having a given amount of coated surface.

The results are only approximate, especially those by the first method, for the following reasons. Length of spark is not a true index of energy; since a short, thick spark may have greater energy than a long, thin one: and our estimate of the comparative energy of each from its appearance, and the accompanying snap, is liable to be very inaccurate. The spark accom-

Fig. 30—Lane's Unit Jar.

panying the discharge of a Leyden jar or battery is generally quite short, though its energy often greatly exceeds that of any single spark of much greater length, given by the machine in charging it.

The humidity of the air and its electric potential, being liable to great variation, produce a corresponding variation in the results obtained at different times.

The charge and discharge of a Leyden jar of a given capacity, in a given time, is a more reliable method.

The jar should be made self-discharging, by bringing the knob of a conductor, connected with its outer coating, within sparking distance of the knob of the jar.

Lane's unit jar, shown in Fig. 30, is constructed on this principle.

A bent brass rod is connected by a band to the outer coating; its upper end terminating in a ball through which passes a horizontal sliding rod, terminating in a ball at its inner extremity; and having an ebonite handle at its outer extremity, by which the ball can

Fig. 31—Electric Chime.

be adjusted to any required distance from the knob of the jar.

To estimate the comparative energy of different machines, a uniform rotation of the plates must be maintained by a given number of revolutions per minute; and the number of discharges in a given time of the unit jar, connected with the

prime conductor, will then be approximately correct for the energy of each.

THE ELECTRIC CHIME.—This instrument is used in connection with the machine, to illustrate electric attraction and repulsion.

It may be mounted on a separate stand, or hung from the projecting rod of the prime conductor. Fig. 31 represents a common style used in this way.

It consists of three bells suspended from a brass rod; the two outer ones by brass wires or chains, and the central one by a silk cord; a brass chain connecting it

with the earth. Between the central and outer bells are two small brass balls, suspended by silk cords.

When the machine is put in operation, the outer bells receive a charge from the prime conductor; this acts inductively on the insulated balls, which are at zero, attracts, and, after contact, repels them. Being now charged the same as the outer bells, they act inductively on the central bell, repelling or attracting electricity through its chain, according as their charge is positive or negative; and producing on it a charge of the opposite kind, they are attracted to it and discharged. Being now at zero, they are attracted to the outer bells, as before; and in this way the three bells are made to ring.

IMAGE PLATES.—

These are used to show the effect of induction between two conducting surfaces, as represented by Fig. 32.

Fig. 32—Image Plates.

From the projecting rod of the prime conductor, a brass plate, having a resistance rim, is suspended by a wire or chain: and under it, on an insulating stand, is placed another similar plate, made a little larger, and joined to the insulating support by a sliding rod, by which the distance between the plates may be adjusted, a chain connecting it with the earth.

When the machine is put in operation, the upper

plate will have the same charge as the prime conductor. If the charge be positive, electricity is repelled by induction from the lower plate to the earth, through the chain; if negative, it is attracted through the same medium; and, in either case, the plates are oppositely charged to the same potential, the air being the dielectric.

When the space is properly adjusted, pith balls or images, placed on the lower plate, are alternately attracted and repelled, dancing up and down between the plates in a manner which is often quite amusing.

Fig. 33—The Electric Whirl.

If electric connection with the earth be severed by removing the chain, this effect will cease: which proves that the opposite potentials of the plates was caused by the transfer of electricity to or from the earth, as stated.

THE ELECTRIC WHIRL.—This little instrument, shown in Fig. 33, consists of a set of pointed brass arms attached to a common center, which is pivoted on the point of a vertical rod connected with the prime conductor; the arms being bent, so that when passing a given point each shall turn in the same direction.

When the machine is put in operation, the air in front of each point becomes electrified, either positively or negatively, by the passage of electricity either from or to the point; while that back of it is oppositely electrified by induction. This causes repulsion from the air in front, and attraction toward that at the back,

producing rotation of the instrument in the opposite direction to that in which the points turn.

The effect of a stationary point in producing a current of air is shown in Fig. 34; where the flame of a candle is represented as blown from a point attached to the prime conductor.

The direction of the air current will be the same whether the charge is positive or negative: since, in either case, the air embraced within a sphere of which the point is the center will have the same potential as the prime conductor; while that outside of this sphere will assume the opposite potential by induction. Hence the air near the point becomes self-repellent, and is also attracted by the air outside; that directly in front of the point being repelled

Fig. 34—Air Current from a Point.

with the greatest force, produces a current in that direction, while the air on either side is attracted, and, in its turn, again repelled.

ARMSTRONG'S HYDRO-ELECTRIC MACHINE.—Fig. 35 represents a machine invented by Sir William Armstrong, about 1840, which generates electricity by the discharge of partially condensed steam.

It consists of a boiler and furnace mounted on glass pillars; the boiler being provided with steam and water gauges, a safety valve, and a condenser inclosing several small pipes, through which the steam escapes.

These pipes are surrounded with filaments of cotton,

the lower ends of which are immersed in cold water at the bottom of the condenser: and the water being thus raised by capillary attraction, cools the pipes, producing partial condensation of the steam; thus charging it with water in fine drops, by the friction of which against the pipes electricity is generated; the steam

Fig. 35—Armstrong's Hydro-Electric Machine.

being discharged against a row of points connected with the prime conductor.

Each pipe is furnished with a wooden tip: and the friction is increased by a tongue of metal, around which the steam must pass before entering the tip, as shown by the enlarged section at letter A.

A machine of this kind, constructed for the Royal

Polytechnic Institution in London, had a boiler seventy-eight inches long, and forty-two inches in diameter, with forty-six steam jets. It gave sparks twenty-two inches in length, and charged to its full capacity, in six to eight seconds, a Leyden battery, having eighty square feet of coated surface.

Another one, described by Noad, had one hundred and forty steam jets, gave sparks of the same length, with three or four times the rapidity; and charged, to its full capacity, a Leyden battery having 1,188 square feet of coated surface, sixty times in a minute.

But though capable of such powerful effects, this machine is not practical. It is inconvenient to manage, requires distilled water, careful cleansing of the boiler after use, and great steam pressure. Its operation is accompanied with a deafening noise, and the escape of a great volume of steam, producing dampness and other unpleasant results, when used in a room. Hence its chief value is in the demonstration of the important fact, that electricity may be generated in this way.

CHAPTER VIII.

ELECTRIC GENERATORS.

THE HOLTZ AND TÖPLER MACHINES.

INFLUENCE MACHINES.—Previous to 1865, frictional machines were the principal electro-static generators in use. But that year marked an era in electric progress by the invention of two new machines of remarkable energy, by the German electricians, Holtz and Töpler; to which the name *influence* machines was given, from their being constructed with two or more glass plates, arranged to generate electricity by their mutual inductive influence.

Both machines are very similar in construction; the principal difference being, that the Holtz requires to be incited by an initial charge from an external source, while the Töpler is self-inciting.

THE HOLTZ MACHINE.—This machine, of which there are several different styles, is represented by Fig. 36. On a wooden base are mounted two glass plates; the rear plate *B* stationary, and supported by three ebonite insulators, two below and one above; while the front plate *A* revolves in the direction of the arrow, on a steel shaft, which passes through an opening in the center of the plate *B*, and is attached to the post at *M*. *A* is mounted on an ebonite hub, attached to a hollow shaft of brass, which revolves on the fixed shaft, and carries, at the end next the post, a small pulley, from which a belt extends to the driving wheel, which

is revolved by a crank with an ebonite handle. The relative sizes of the wheel and pulley are such as to give the plate four to six revolutions for each revolution of the driving wheel, the plates of small machines requiring a more rapid revolution than those of larger ones. In front of the plate *A*, $\frac{1}{4}$ of an inch from the glass, are the combs *V* and *H*, attached to a brass core at the center of the ebonite disc *M*; and the combs *K* and *L*, insulated by their attachment to ebon-

Fig. 36—The Holtz Electric Machine.

ite rods projecting from the disc *M*, and connected by brass rods with the Leyden jars *C* and *D*, and with the sliding-rods *P* and *R*. These sliding-rods have ebonite handles, and terminate in brass balls at their inner extremities.

The plates are of sheet glass, about $\frac{1}{8}$ of an inch thick; of good insulating quality, and well coated with shellac. The stationary plate *B* has two circular openings called

windows, directly opposite the combs K and L ; and, on its rear surface, are cemented two paper inductors T and X ; T extending from H to L , and X from V to K ; and each armed with a row of points, projecting into each window.

Machines of this kind are often constructed with more than two plates; sometimes with a large number. The plates are also sometimes placed in a horizontal position. Ebonite plates are also used; but are objectionable, for reasons already given.

THE TÖPLER MACHINE.—The Töpler machine has the same general construction as the Holtz; but, on the front surface of the revolving plate, are cemented a number of small metal discs, called *carriers*; usually made of tin-foil with raised brass centers, which, as the plate revolves, are brought into contact with four wire brushes; two attached to the stationary plate, and two to the uninsulated combs. In this way the machine is made self-inciting, as already mentioned.

The windows, and the rows of points projecting into them, used in the Holtz stationary plate, are omitted from the stationary plate of the Töpler: and the paper inductors are made longer, and have small tin-foil inductors under them, connected, by tin-foil strips, with each other and also with the two brushes attached to this plate.

Fig. 37 represents a Töpler machine constructed by the author, and patented April 10, 1883, and December 8, 1885. The principal points covered by the patents are as follows:—

1. The outside coatings of the Leyden jars C and D are of sheet brass, nickel plated; and are screwed firmly to the base; forming cups into which the jars

fit closely, and are thus held in a fixed position ; affording a firm support to the parts connected with them, and preventing liability to accident or injury to the jars or plates.

2. The induced current from these outside coatings is conveyed down by the brass screws which attach

Fig. 37—Atkinson's Töpler Electric Machine.

them, and along copper wires underneath, to the terminals of the switch *S*; through which, when closed, it passes from one jar to the other ; but when open, as in the cut, it passes by the brass sockets, seen on the edge, which are also connected with the terminals, out through the conducting cords, and a person, or other

object, connected with their outer extremities. As this induced current flows simultaneously with the direct current from the inside coatings, the switch and sliding-rods place it completely under control of the operator.

3. The brush holders, *E* and *F*, are attached to the plate *B*, through holes near its edge; thus giving a direct passage to the electricity from the carriers on the plate *A*, where it is generated, through the glass, to the tin-foil inductors, represented by the dark shade, and the paper inductors *T* and *X*, represented by the light shade. By passing the electric charge *through the glass, inside its edge*, an insulating margin is interposed between the conductors and the edge, thus preventing loss from leakage, which is unavoidable when the brush holders are attached by clamps or ears *on* the edge.

4. The carriers on the plate *A* are of sheet brass, with raised centers, and are nickel plated, making them both durable and ornamental. The hard nickel surface is not affected by the action of the brushes, or the electricity, while tin-foil soon becomes defaced: and the carrier, being practically one piece, and its entire surface cemented to the glass, its raised center cannot become detached, as may happen when the center is put on separately over a tin-foil base.

5. The combs *V* and *K*, also *H* and *L*, radiate at an angle of 45 degrees to each other, from the central disc *M*, to which they are attached; so that any possibility of error in regard to their position, or of displacement, is practically impossible.

The following improvements may also be noticed:—

The base is made of two-inch strips, glued together lengthways, and heavy cleats screwed on underneath; giving all the advantages of iron as to freedom from

warping, with the insulation and elegant finish of the wood. The driving wheel is of ebonite and the iron casting, on which it is mounted, slides in grooves on an iron plate, and is moved by the adjusting screw *O*, to regulate the tension of the belt.

Fig. 38—Atkinson's Four-Plate Töpler Machine—Front View.

The ebonite insulators, which support the plate *B*, have soft rubber packing, to ease the pressure on the glass.

The conducting rods of the Leyden jars pass through ebonite caps with cork attached underneath, which gives them a fixed vertical position, and affords firm support to the sliding-rods and the combs connected with them above.

THE FOUR-PLATE TÖPLER MACHINE.—This machine has the same construction in front as the two-plate machine as shown by Fig. 38, but a special construction for the two rear plates which will be understood by reference to Figs. 39 and 40.

The end view, Fig. 39, shows two pairs of plates, the position of the rear pair being reversed, which brings the stationary plates into the center, back to back, be-

Fig. 39—Atkinson's Four-Plate Töpler Machine—End View.

tween the revolving plates ; so that the inductors are on the inner surfaces of the stationary plates, and the carriers on the outer surfaces of the revolving plates, which being mounted on the same shaft, with a collar between them, revolve in unison.

The combs *L* and *K*, and *V* and *H*, have curved rods which pass round the plates and support duplicate combs in the rear as shown in the cuts. The brushes are also duplicated as shown : so that with the exception of the Leyden jars and switch, and parts connected with them, this is practically a double machine.

In like manner an eight-plate machine may be made by doubling these parts of the four-plate.

When the large Töpler or Holtz machines are wanted for constant use, the motive power is usually supplied by a steam or gas engine, or a water motor.

In which case the driving wheel is not used; the belt passing directly from the small pulley connected with the plates, to a pulley attached to the engine or motor.

MODE OF ACTION OF THE TÖPLER.—To comprehend the action of any electric generator, the following essential principles in their construction should be kept distinctly in view.

To generate electricity, is to create a difference of electric potential; the efficiency of all generators,

Fig. 40—Atkinson's Four-Plate Töpler Machine—Rear View.

whether batteries, dynamos, or glass plate machines, depending on the difference of potential which each is able to create and maintain within the apparatus itself. And the work to be done by such an apparatus is the restoration of equilibrium, through an exterior circuit; and may consist in producing heat or light, chemical, mechanical, or physiological action.

Let us consider how these principles apply to this machine.

Fig. 37, page 111, represents the machine with the sliding electrodes *P* and *R* separated. Suppose the switch *S* to be closed and the machine put in operation. It will be seen that as the plate *A* revolves, the raised centers of the six carriers are brought into contact with the wire brushes attached to the holders *E* and *F*; each opposite pair touching opposite brushes, successively, at the same instant. The friction generates electricity, which diffuses itself over the carriers on *A*, and the inductors on *B*, with which they are, at the instant of contact, in electric connection. The potential of carrier and inductor, during contact, will be the same; at the next instant the carrier passes on, and is insulated from the inductor, and carrier and inductor now act inductively on each other, and multiply the initial charge given by the friction of contact. As it accumulates, it spreads over the paper inductors; these act on the opposite surfaces of the glass, till both surfaces of both plates become charged; the initial charge being still continued by the constant friction of the carriers and brushes.

But, since both sides of the machine are of similar construction, and since the mode of action on both sides is apparently the same, the question arises, how any difference of potential, or electric charge can be accounted for.

And first, it will be noticed, that the position of the plates being vertical, their lower halves are nearer to the earth, by their semi diameter, than the upper halves, and consequently, more under the influence of its inductive action, by the square of that distance. The lower halves are also in close proximity to the Leyden jars, the driving wheel, and the belt, and subject to their

inductive influence; and the plate *B* is supported on *two* insulators, while the upper half has but *one*, and hence has the advantage of the better insulation of the air.

To this lower half of *B*, and subject to these influences, is attached the brush holder *F*, while *E* is attached to the upper half, and remote from them. Hence, the carriers brushed by *E*, and descending towards *L*, must acquire a higher potential than those brushed by *F*, and ascending towards *K*.

An accumulation of electricity must also occur at the lower ends of the inductors *T* and *X*, from the inductive influence of the earth; and as the brush holder *F* is placed at the lower end of *X*, it furnishes an outlet to a portion of this charge, as seen at night by the brushes of light from this holder to the outside of the jar *C*, and other parts in close proximity.

The lower end of *T*, on the contrary, is well insulated; hence the potential of *T*, from the heavier charge at its upper end, and the better insulation at its lower end, must be much higher than that of *X*, where the influences are just the reverse.

This accumulation, or high positive potential at the lower end of *T*, produces a high negative potential at that point on the plate *A*, and its carriers, as it revolves; as shown by the brush of light, seen in the dark, from the uninsulated comb *V*, marking the flow of electricity to the upper part of the plate, as it passes under that comb; the outflow of the current received through the comb *H*. This brush of light extends downward, as the charge increases, almost to the comb *K*: and a similar brush extends downward from *K*, marking the outflow of electricity from the interior of the jar *C*, as explained hereafter: while the points of the combs, *L*

and H , where the charge is received, show only a glow of light.

These brushes of light always turn in the opposite direction to that in which the plate A revolves; difference of potential between the comb and that portion of the plate approaching it producing attraction; while equality of potential between the comb and that portion of the plate receding from it produces repulsion. (See p. 224.)

Following any opposite pair of carriers, as W and Z , we find that as Z passes under the wire brush F , W passes under E ; and as Z moves on to the insulated comb K , W at the same instant arrives at L ; but W , as already shown, has a higher potential than Z , and, at this point, a peculiar adjustment takes place. W gives up its charge through the comb L , to the inside of the Leyden jar D . This creates a positive charge on the inside of D , which induces a negative charge on its outside. The electricity thus repelled, passes to the outside of C , making it positive, and inducing negative on its inside; and this repelled electricity flows through the comb K to the plate A , as already shown. W then moves down to the uninsulated comb H , while Z moves up to V . Each now passes under the wire brush attached to its respective comb, and the combs being attached to the brass core at the center of M , the carriers are put in electric connection with each other, and their potential equalized by the flow of the residual charge from H to V , as already described; so that each arrives at the original position of the other at the same potential, ready to repeat the same process.

It should be noticed, that the residual is slightly increased by induction from T and X , as the carriers move from the combs L and K to the combs H and V .

The surfaces of the plates, on which the carriers and inductors are mounted, assume the same potential as the carriers and inductors attached to them, while their opposite surfaces have the reverse. Opposite parts of the same surface are also in opposite electric states: the section $L M H$, for instance, having a potential opposite to that of $V M K$; change of potential on these surfaces following that of the carriers and inductors, already described.

It will be noticed that the office of the brushes, E and F , is the reverse of that of H and V . E and F generate by friction, while H and V discharge by contact. And, while the combs, K and L , aid in creating a difference of potential, the combs, H and V , aid in restoring equilibrium.

When the difference of potential between the inner coatings of the jars becomes sufficient to overcome the resistance of the air, a discharge from the inner coating of D to that of C takes place between the terminals of the sliding electrodes R and P ; and, at the same instant, a discharge from the outer coatings takes place through the switch and connections, from C to D , to restore equilibrium between them, and thus complete the circuit.

A spark and snap, from the resistance of the air, accompanies the discharge between the inner coatings; and the same will occur between the outer coatings if the switch is open; but, if closed, the discharge takes place silently. The plates and other parts being, at the same instant, relieved of strain, there is a restoration of equilibrium in the whole machine.

The above explanation applies to the machine when it is put in operation from a state of absolute rest; but

when it is in a high state of activity, there frequently occurs a reversal of potential after a discharge, as shown by the reversal of the brushes of light from the combs. To account for this it must be considered, that the residual which remains after the primary discharge may, from unequal resistance, be greater on one side than on the other; and after being relieved from strain by the primary discharge, it will operate to give a slight preponderance of potential to that side, which is rapidly multiplied by induction, as the rotation of the plate continues.

A reversal can also be produced by a temporary reversal of rotation, as explained on page 140; or by touching the inductors, or parts connected with them, while in action, which would reduce the potential at that point. Special conditions may also exist in certain machines, which will reverse the ordinary mode of action; as, for instance, a difference of thickness on opposite parts of a glass plate; or in opposite jars.

It should be noticed that the electric charge is instantly diffused over the metal carriers and inductors, more slowly over the paper inductors, and still more slowly over the shellacked surfaces of the glass plates. So that when the machine is put in action, after a considerable interval of rest, three or four seconds elapse before it becomes fully charged, and a crackling sound is heard from the electricity forcing itself over the resisting surfaces of the paper and glass.

The condition of the air, as to its insulation, influences the whole operation of this machine. An air space insulates the plates, and also the jars, with their rods and balls, from each other; and as a damp atmosphere lessens this insulation, it will decrease the energy

of the machine in like proportion. A film of moisture, settling on the plates, will often so reduce the insulation, that the slight initial charge by the action of the brushes is conducted over the damp surface as fast as it is generated; so that no difference of potential, and consequently no permanent charge, can occur. And as the machine is much more sensitive to such influences than the operator, the latter is often puzzled to know why it will not generate. The simple and effectual remedy, in all such cases, is to dry it. This may be done by a fire, a kerosene lamp, a hot iron, or by the sun's heat, though artificial heat is generally more effectual.

Warm days, before or after rain, when the atmosphere is loaded with moisture, are the most unfavorable. At such times the plates should not only be dried, but warmed, as moisture will continue to be deposited so long as they are colder than the air.

The electric conditions in upper rooms, other things being equal, are more favorable to the operation of the machine than in those on the ground floor.

MULTIPLICATION OF THE CHARGE.—The multiplication of the initial charge proceeds with great rapidity. During the first revolution of the plate *A*, each tin-foil inductor receives six direct charges from the contact of its connecting brush with each of the six carriers: and also six inductive charges of equal amount, as each charged carrier passes it. So that at the end of the first revolution, it has accumulated twelve charges; and, during that revolution, it has reacted inductively on each passing carrier with this constantly increasing energy, increasing the energy of the carrier in like proportion.

At the beginning of the second revolution, it has

twelve times the inductive energy which it had at the beginning of the first; and this energy continues to increase, and react on the carriers, at the same rate as before. And as the plate makes about five revolutions per second, the rate of increase on any tin-foil inductor is about sixty increments per second.

But as the charge spreads from the tin-foil inductors over the paper inductors and adjacent parts of the stationary plate; and from the carriers over adjacent parts of the revolving plate, each point on each plate, within the charged areas, becomes a center of direct and inductive action in the same manner as the metal inductors and carriers. So that even an infinitesimal charge is increased in a few seconds to the full capacity of the machine.

HOLTZ AND TÖPLER MACHINES COMPARED.—Since the chief difference between the Holtz and Töpler consists in the latter being self-inciting, the mode of action is essentially the same in each.

The Holtz may receive its initial charge from a frictional machine, an electrophorus, or any similar, external source: but the usual method of charging is by means of a piece of ebonite, electrified by the fur of a cat-skin.

The electrified ebonite is held in contact with one of the paper inductors on the stationary plate, which is thus charged; a portion of the charge being communicated to the revolving plate through the points which project into the windows; and this plate is made to rotate rapidly, so that the charge is soon multiplied to the full capacity of the machine, if the atmospheric conditions are favorable; and the ebonite is then removed.

It will thus be seen that the initial charge in both machines is produced by friction and multiplied by

induction. In the Holtz it is derived from an external source, begins on the stationary plate, and is then communicated to the revolving plate. In the Töpler it is produced by the machine itself, begins on the revolving plate and is then communicated to the stationary plate. In the Holtz it occurs on one side only. In the Töpler it is simultaneous on both sides. In the Holtz it ceases when the plates are charged. In the Töpler it is continuous.

The absence of the brushes, carriers, and metal inductors from the Holtz increases the internal resistance, making it more difficult to charge, but giving better insulation, and consequently greater energy than a Töpler of the same size.

But the action of a Holtz is much more liable to interruption from dampness, and a low electric potential in the atmosphere: since it receives only a small initial charge, which is soon discontinued; while that of the Töpler is constant, from the continuous action of the carriers and brushes. So that a well constructed Töpler, with ordinary care, is reliable in any state of the atmosphere, while a Holtz is very unreliable.

COMPARISON BY DR. HOLTZ.—In reply to an inquiry as to whether the Töpler machine was an original, independent invention, or only a modification of the Holtz, the author received a letter from Dr. Holtz, written from Greifswald, Germany, March 20, 1883; in which he says, that his machine, as first described in Poggendorff's *Annalen*, in 1865 (volume 125, page 469, and volume 126, page 157), had "two discs rotating in opposite directions, without stationary discs"; and that "The Töpler machine, invented at the same time, was a combination of two pairs of discs"; two movable and two stationary.

He then says:—

“Töpler has recently rejected his system and adopted mine, because it is simpler, and, at the same time, more effective. The application of the pointed combs and the non-covered movable discs is also *my* invention, since the Töpler machine had only the tin-foil coverings and sliding springs. (*Schleifende Federn.*)

“I had been accustomed to the same, indeed, already; although not with independent acting, influence machines, but rejected them on account of the smaller spark-length.

“Töpler has also lately adopted my principle of the pointed combs, and the non-covered discs; but so far modified, that *besides* the pointed combs and non-covered discs, he yet allows to act, at the same time, small pieces of tin-foil (or pieces of metal), and the sliding springs. This has the advantage that the machine excites itself, and is less sensitive to moisture; but also the great disadvantage, that the sparks become shorter, and a constant reversal of current follows. Besides, a certain mechanic, Voss, also claims this machine, so modified, as his merit; but unquestionably Töpler was the first who showed that influence machines, with metallic covering and sliding springs, excite themselves.

“The entire form of the machine, its symmetrical construction, the one-sided support of the axis, the application of a sheath running upon a pin fastened on one side, the application of the so-called rotary diametrical (double) pointed combs, the application of the so-called condensers (small Leyden jars) for increase of spark-length, is all mine, as published in the year 1869, by Professor Poggendorff (Poggendorff's *Annalen*, vol. 136, page 171).

“Yours truly, Dr. W. HOLTZ.”

The “sliding springs” mentioned above, doubtless refers to a style of construction in which the springs glide continuously over the surface of the glass; essentially different, and differing in its effect, from that of the brushes, which touch only the raised centers of the carriers, and are wholly insulated from the glass; giving alternate contact and insulation, making induction much more effective. The latter construction is attributed to Voss.

CHAPTER IX.

EXPERIMENTS WITH THE TÖPLER MACHINE.

IN experiments with the frictional machine, such as the charging of Leyden jars, and the ringing of bells, as already described, induction is produced by connecting one part of the apparatus with the earth, and another part with the prime conductor. But in the Holtz and Töpler, the charge is accumulated in the Leyden jars instead of on a prime conductor; and any change of potential in one jar must be compensated by a corresponding inductive change in the opposite jar. Hence to obtain the full inductive effect, connection must be made with the opposite jars.

For convenience in making this connection, holes are drilled in the knobs surmounting the jars, and the charge is conveyed by insulated conducting cords, having brass tips which fit these holes.

Thus, by connecting the inner and outer coatings of a Leyden jar or battery with the opposite jars in this way, a full charge can be given very rapidly.

In a similar manner, image plates, bell chimes, and other apparatus, mounted on separate stands, can be connected and used.

ELECTRIC CHIME FOR TÖPLER MACHINE.—Fig. 41 represents a chime designed by the author, which is mounted on the machine itself. It consists of two brass arms *A* and *B*, insulated by an ebonite connector

C; the tips of the arms being fitted to the holes in the knobs of the jars.

A bell is suspended from each arm by a brass rod; and a brass ball suspended by a silk cord from the ebonite connector hangs between them.

As each bell is at the same potential as the jar with which it is connected, the ball is alternately attracted and repelled, causing the bells to ring.

Instruments of this kind have no practical use, except to illustrate the principles of the science.

Fig. 41—Chime for Töpler Machine.

APPARENT TIME OF THE ELECTRIC DISCHARGE AN OPTICAL ILLUSION.—The carriers on the revolving plate of a Töpler afford special facilities for this experiment. They are usually six discs, arranged in a circle, and present the appearance of a continuous bright ring when

the machine is operated in the light; but when operated in the dark, they are seen only when the spark renders them visible; and, instead of the bright ring, each appears by itself, apparently motionless, and as perfect in form as if really so, just as if the movement of the plate were momentarily arrested during the passage of the spark.

This apparent time of the spark may be estimated at $\frac{1}{4}$ second; but if the carriers were really visible during that time, the ring-like appearance would be

unavoidable, as will appear from the following calculation.

Suppose the revolving plate to have an average speed of $4\frac{2}{3}$ revolutions per second, it is evident that each carrier would make a complete revolution in less than $\frac{1}{4}$ second; consequently if that were the actual duration of the spark, each would be continuously visible round the entire circle, and hence even a single carrier would produce the bright ring. But it is only necessary to this result that each should be visible until it takes the place of its predecessor—that is during its passage of $\frac{1}{6}$ of the circle, which reduces the time to $\frac{1}{24}$ of a second.

But if they were visible even half that time, $\frac{1}{48}$ of a second, and each were $1\frac{1}{2}$ inches in diameter, and their distance, from center to center, 6 inches, we would have 6 ellipses, each having a length equal to twice its breadth.

From this it is evident that the smallest conceivable duration of spark must produce an ellipse: but as each presents the appearance of a circle, with no tendency to elliptical form, the conclusion is inevitable that the apparent duration of the spark is an optical illusion, and that its time is so nearly zero, that it cannot be estimated.

We must conclude, then, that at the instant of discharge the image of the carrier is photographed on the retina of the eye, and at the next instant darkness supervenes: but the sensation on the retina has a momentary duration, during which the carrier appears stationary, while in reality it may have passed entirely round the circle.

It is important to notice, in this connection, that the appearance and disappearance of the carriers depend

on the rapidity of the discharge; and when the spark is made so short and rapid as to be apparently continuous, the carriers appear and disappear with each snap, like a succession of views in a rapidly moving panorama, proving that the apparently continuous spark is a succession of sparks so rapid as to give the impression of continuity.

As a flash of lightning is only the same thing on a grander scale in nature's own laboratory, we must conclude that the passage of electricity from cloud to cloud, a distance often of many miles, is so rapid as to defy human calculation. We notice this in chain lightning, when the flash, sometimes three to five miles long, is seen throughout its entire length at the same instant, as if suddenly photographed on the cloud.

TRANSMISSION OF POWER BY STATIC ELECTRICITY.

—Two machines are necessary for this experiment—one called the primary, and the other secondary. The secondary should be a very light running machine; hence it is better to make it smaller than the primary, and the driving wheel and switch may be dispensed with.

Let the machines be placed near each other, in the same relative position, the secondary in front; and connected together by conducting cords or wires, joining similar pairs of Leyden jars: and let the sliding electrodes be separated beyond sparking distance. Now let the primary machine be put in operation, and the movable plate of the secondary will rotate in a direction opposite to that of the primary. If the electric energy should not be sufficient to overcome the friction and inertia, in starting, the plate of the secondary may be put in rotation by hand, and its motion will then be sustained by the electric action.

The explanation is as follows. When a Töpler machine is in operation, there is a strong attraction between the plates, the result of induction from the opposite electric states of the parts in proximity. This attraction which constantly increases up to the instant of discharge, acts as a resisting force which must be overcome by the force used to rotate the plate. Now, when the two machines are connected, this electric force is transmitted to the secondary, where, having no mechanical force to oppose it, as in the primary, it causes the rotation of the plate in the opposite direction.

Thus the mechanical force in the primary is transmuted into electric force, passes over to the secondary and reproduces mechanical force; the force applied to the primary being expended in the secondary.

The apparatus thus becomes a scientific bank, with its receiving and paying tellers. But nature is a shrewd banker, and always exacts full discount; hence the mechanical energy, paid in to the primary, is discounted by friction, leakage, and heat; so that the remaining energy may not be sufficient to start the plate of the secondary into rotation without an additional payment.

The sliding electrodes in the secondary machine may be adjusted to produce the electric discharge with spark and snap, instead of the mechanical rotation of the plate; thus illustrating the transmutation of force, at will, from mechanical to electric, and from electric either back again to mechanical, or to the heat, light, and sound of the electric discharge.

SOURCE OF ELECTRIC SUPPLY OF THE TÖPLER MACHINE.—The earth, the machine itself, and the air are

the only sources from which an electric machine can derive electricity.

With the common friction machine a connection with the earth is indispensable, and only a very limited charge can be obtained without it; the transfer being either from the earth to the machine, or from the machine to the earth, as explained on page 99. Hence it is often compared to a pump, drawing electricity from the earth through a chain. Remove the chain and the supply ceases.

But with the Töpler a similar earth connection diminishes the charge; showing a loss instead of an increase of charge. Indeed, perfect insulation of the generating parts is an essential feature of the machine.

To demonstrate this more perfectly, let the machine be put in operation on an insulated platform, when it will be found that there is not the slightest perceptible diminution of electric energy. It is evident, then, that the earth is not its source of supply.

A certain amount is, no doubt, obtained from the material of the machine itself; but this source would soon be exhausted by such experiments as the charging of a large Leyden battery; whereas such a battery may be charged without diminishing the energy of the machine.

The air, then, is the only remaining source, and the large amount of ozone generated by this machine is conclusive evidence of its electro-chemical action on the air, and strong, presumptive evidence that the air, thus acted upon, has furnished the electricity whose action has changed the oxygen to ozone.

This would imply that ozone is the result of depriving air of a portion of its electricity; whereas if the

electricity were derived from the earth, we must infer that its generation precedes the generation of ozone, instead of being coincident with it. But the insulation proves that the earth does not supply the electricity; so that the weight of evidence is in favor of ozone being the direct result of electric generation, rather than a result of subsequent electric action. And, if such is the case, it is strong proof that the air is the chief source of electric supply.

The generation of ozone by atmospheric electricity during thunder storms is a well-known fact; and clouds, floating miles above the earth, must obtain their electricity either from their own vapor, or the air, or both. Such clouds, at different electric potentials, insulated from the earth, acting inductively on each other, and finally producing a discharge, fulfill the same conditions as exist in the Töpler machine; and the generation of ozone is doubtless due to the same cause in both. And since the vapor of the cloud corresponds to the material of the machine, and it has been shown that the electric supply of the machine from its own material must be very limited; and since the machine operates most effectively in a dry atmosphere, and hence does not derive its electricity from vapor; we may infer that the electric action is the same in both cases, and that the air is the chief source of electric supply.

It is evident from the movement of particles of dust and other light bodies towards the machine, that the air in which these atoms float must have a similar movement; that currents of air are constantly flowing to the machine and that this air, after being changed to the same electric potential, is repelled, and air at a different potential flows in to take its place; a move-

ment similar to that which takes place in the hot and cold currents round a heated stove.

But the initial charge is undoubtedly from the material of the machine itself, and results from the friction of the brushes on the carriers; after which follows the increase by induction and the action on the air.

ELECTRICITY GENERATED BY THE FRICTION OF METALS.—The old division of all substances into electrics and non-electrics was the exponent of the idea then prevalent, that only certain substances, as glass, sealing-wax, and other non-conductors, comprised in a very brief list, were capable of electric excitation. While this view is no longer maintained, yet, since in nearly all experiments illustrating the elements of static electricity, glass, sealing-wax, ebonite, silk, wool, fur, and other non-conductors, are almost exclusively employed as generators, we are apt to lose sight of the fact that metals and other conductors are capable of generating electricity by their mutual friction. And yet this is one of the most important principles of static electricity. It is that which liberates our ideas of electricity from the narrow bounds to which they were once confined, proving that it is not a special property of certain substances, but a universal property of matter, one form of that energy which pervades and controls the universe.

This point has been already illustrated, but the Töpler machine affords special facilities for illustrating it more fully. In it the initial charge is produced by the friction of metal brushes on metal carriers. True, both carriers and brushes are attached to glass, and the glass subsequently acts by induction as a generator; but the friction is confined to the carriers and brushes

alone; and, so far as the electricity is obtained from this source, the glass acts only as an insulator to prevent the escape of the electricity generated by the friction, from which the initial charge is derived.

It is not even necessary that the metals should be different. The machines here described are constructed with brass carriers, and brushes of brass wire; and, though the carriers are nickel-plated, so that the friction is that of brass brushes on a nickel surface, yet carriers left unplated give equally as good results.

THE SPARK; ITS DIRECTION, SUBDIVISION, AND COLOR.—The spark from a Töpler machine presents phenomena which demand careful investigation.

As already shown, the apparent time of the discharge is an optical illusion, time being practically annihilated; so that it is impossible, from observation, to tell in what direction the discharge takes place. A brilliant streak of white light, extending from one electrode to the other, suddenly appears and disappears, leaving us in ignorance as to the direction in which it moves. But the following experiment affords better opportunity for observation.

As already shown, the electric connection between the inside coatings of the Leyden jars may be interrupted by separating the sliding electrodes, and that between their outside coatings by opening the switch. Put the machine in operation in a darkened room at night, with the switch open, and the sliding electrodes separated three or four inches. From the electrode *P*, Fig. 42, a brush of violet-colored light, diverging from a small, circular space, extends about $\frac{3}{4}$ of an inch towards the opposite electrode, accompanied by a hissing sound. The opposite electrode, *R*, remains comparatively qui-

escent at first, showing only a glow of light; but, as the electricity accumulates, there is a sudden outburst from it, accompanied by phenomena of the most interesting and varied character.

A brush of light, of a faint white, or violet color, darts across the intervening space, diverging towards the center, and converging as it meets the brush from the opposite electrode; forming an elliptical figure, two or three inches in diameter, extending from one electrode to the other. Through the center of this brush shoot out long tongues of red and violet light, curving and branching in a variety of fantastic forms. Sometimes five or six of these appear at once, like fiery serpents, hissing, spitting, and darting out their red forked tongues. Sometimes the appearance is that of a miniature tree, its main trunk branching off at various angles and curves. Then, again, the brush disappears, and we have a single, straight, violet colored stem, about $\frac{3}{4}$ of an inch long, which divides into a great number of bright rays, radiating in straight lines from the end of the stem, and forming a globe of white light, about three inches in diameter: the whole resembling a little bush of remarkably regular appearance, in marked contrast with the curved and contorted phenomena just described.

Between this, and the short brush on the opposite electrode, a dark space intervenes, into which the rays pass and intermingle; the brush from the electrode *R* being largely in excess of the other, and showing far greater energy; but more fitful, coming at first in jets, with a spitting sound, while the other is more constant, with a steady, hissing sound.

As explained on page 118, electric movement is from

the comb *L* downwards into the jar *D*, then along the switch, when closed, and its connections to *C*, and upward out of *C* to the plate and carriers; and, in part, along the electrode *P* towards *R*, which connects with the inside of *D*: the glass of the jars, and the air space between *P* and *R* forming barriers at which electricity

Fig. 42—Experiments with the Töpler Electric Machine.

accumulates on the side towards which the movement takes place, induction producing a corresponding negative on the opposite side.

D has the higher potential, as already shown, but its inside charge is bound by an equal negative on its outer coating; while electricity is repelled from the

inside of *C*. Hence, when the switch is open, we have the difference in the brush discharge already described.

But as the higher charge of *D* continues to accumulate on its inside coating, the tension increases on the electrode *R*, till the electricity finally bursts through the resisting air from *R* to *P*; producing the spark and snap when the switch is closed, as already explained.

The effect of opening the switch is to substitute for this metal conductor, which has comparatively no resistance, a portion of the base, which is of kiln-dried wood, and offers high resistance. This retards the current, producing the difference of phenomena between the bright, instantaneous spark of white light, with its sharp report, and the slow moving brushes of violet light, with their hissing, spitting sounds; and from this slow movement we are able to determine the direction of the discharge, as already shown.

The cause of the subdivision of the spark when the switch is open next claims attention. It has been shown that the discharge between the inside coatings through the electrodes *P* and *R*, and the intervening air space, is dependent on the counter discharge between the outside coatings, through the switch, when closed, or, through the kiln-dried wood of the base, when the switch is open. This discharge may be seen by opening the switch, half an inch or more, so that the resistance of the air is less than that of the wood. We then have a bright spark below, simultaneous with the spark above. But when the switch is opened so that the resistance of the air is greater than that of the wood, the discharge below takes place silently through the wood, and we have above, the subdivided, colored discharge already described.

With the switch closed, reducing the resistance below to zero, the discharge through the air is instantaneous; and there is seldom any subdivision, except that a long spark from a heavy charge sometimes divides into two, slightly separated during a part of their course. But, with the switch open, the high resistance retards the lower discharge, which is compelled to force its way slowly through the kiln-dried wood; making the change of potential between the outside coatings slow and gradual, and producing a similar effect on the inside coatings. Now, as the spark is caused by the electricity forcing its way through the air, whose electrified molecules are at the same potential near each electrode, and hence self-repellent, while the surrounding air is at a lower potential and attractive, these forces, acting in part at right angles to the original impulse, during the comparatively slow progress of the discharge, produce the brushes of diverging rays already described. Various influences, such as currents of air, particles of dust, and the induction of electricity generated on adjacent parts of the machine, curve and contort the spark, producing the peculiar phenomena already described in connection with the brushes, and also affecting the long bright sparks in a similar manner.

We next notice the color of the spark. Light is a mode of motion, and its color is influenced by the intensity of the motion. A bar of iron, drawn from the furnace, ready for rolling or welding, is said to be at a white heat; as it cools it changes to a red heat. Here the color of the light depends on heat, which is also a mode of motion; and as the intensity of the heat motion decreases, the light changes from white to red of various shades, till the bar resumes its original color.

The brilliancy of the arc in the electric lamp is due to the intensity of the motion, while the softer light of the incandescent lamp results from a motion less intense. When an electric lamp is being lighted or extinguished, the change of color from white to the various shades of red is evidently dependent on decrease of motion. Must we not conclude then that the white light of the electric spark, when the switch is closed, is due to intensity of motion, and the colored light with the open switch, to decrease of intensity, as in the iron bar or the carbon of the electric lamp? Or, if light and heat are modes of motion, is not the evidence equally strong that electricity is a mode of motion? Or may we not go still farther, and say that light, heat, and electricity are only different manifestations of that energy which is a universal property of all matter, of which the experiments here given are an additional proof? For in the electric spark, we have light, heat, and electricity combined.

Having stated that *D* is usually the jar of higher potential, it should be explained, that there is frequently a temporary reversal of potential; and, when this occurs, all the phenomena here described are reversed also. The cause of this reversal will be explained in connection with the following experiment.

DIRECT AND REVERSED ROTATION.—A Töpler machine can be charged only by revolving the smaller plate in a given direction; which, in the machine represented, is shown by the arrow.

The reason is this: In order to store up electricity in the Leyden jars, each carrier must pass from an insulated brush, where it is charged, directly to a comb connecting with a Leyden jar, before it passes to an

uninsulated brush, where it is discharged. Thus the carrier *W*, charged by the friction of the insulated brush *E*, must pass to the comb *L*, connecting with the jar *D*, and give up its principal charge, before passing to the uninsulated brush and comb *H*, where its residual is discharged through the brass rod *H V*, which puts it in electric connection with the carrier *Z*, of opposite potential. Reverse the rotation, and the carrier *W*, starting from *E*, would give up its principal charge to the uninsulated brush and comb at *V*, before reaching the comb *K*, connecting with the Leyden jar *C*, where only the residual would remain. It must also be noticed that the charge is greatly increased, both on the carrier and adjacent portion of the plate, by passing the inductor *T*, attached to the stationary plate *B*; whereas, when the rotation is reversed, the carrier leaves the inductor and passes the space between *T* and *X*, where the induction is almost zero. Thus it is evident that no storage of electricity in the Leyden jars, and hence no permanent charge can be obtained from a reversed rotation.

HIGHER POTENTIAL OF JAR D.—It has been shown, that from the higher position, and hence better insulation of the brush *E*, and upper half of the revolving plate *A*, as compared with the lower position, and consequent inferior insulation of the brush *F*, and lower half of *A*, the potential of the jar *D*, receiving its charge from the former, must be higher, as a rule, than that of *C*, which receives its charge from the latter.

Repeated experiments, made by the author with a number of different machines of this kind, fully confirm this view. The higher potential is shown by the frequent partial discharges between the inside and out-

side coatings of this jar; and, in case of fracture, which sometimes occurs from an overcharge, it is always this jar which is broken: and the fracture always occurs on the side nearest the opposite jar, showing that the charge is attracted to that side, and electricity repelled from the outside coating, creating a sufficient difference of potential between the two coatings to overcome the resistance of the glass and perforate it.

REVERSAL OF POTENTIAL.—It has been already stated that there is frequently a temporary reversal of potential. Such a reversal can be produced, if desired, by joining the electrodes *P* and *R*, and reversing the rotation of the plate till the machine is fully discharged; then separating *P* and *R* while the reversed rotation is continued, and then resuming the direct rotation, when a complete reversal of potential will be found to have occurred, which will continue till again reversed by a similar experiment, or till the machine has had a period of rest. The explanation is as follows:—

When *P* and *R* are separated, and the rotation reversed, the same causes which before operated to raise the potential of *D* above that of *C*, now operate to raise the potential of *C* above that of *D*, but in a very limited degree. For, as already shown, any carrier, as *W*, charged by the brush *E*, would now give up its principal charge to the brush and comb at *V*; but the residual, slightly increased by the inductor *X*, would be given up, through the comb *K* to the jar *C*; while the opposite carrier *Z*, would give up its principal charge at *H*, and carry its residual to the comb *L*, and the jar *D*, after a slight increase by the inductor *T*. But the difference of insulation between the upper and lower parts affect these residual discharges in the same man-

ner as the principal discharges, and hence operate to make the potential of *C*, receiving its charge from above, higher than that of *D*, receiving its charge from below. This residual is not sufficient of itself to bring the machine into action, but it creates a slight difference in favor of *C*, sufficient to sustain a reversal of potential when the direct rotation is resumed.

THE FARADIC CURRENT.—The faradic current consists of a series of electric impulses following each other with great rapidity. It is obtained from the battery and coil by a spring vibrator, which opens and closes the circuit; and from the magneto-electric machine by a revolving electro-magnet and commutator.

Both these instruments have, for many years, been extensively used in medical practice; but the use of a static machine for this purpose is quite recent, and the switch, on the machine here represented, affords special facilities for producing and utilizing this current. In Fig. 42 are shown two sockets, on the front edge of the base, connecting with the terminals of the switch, into which are inserted the tips of conducting cords, to the outer extremities of which may be attached metal handles, as shown, or other electrodes suitable for the use of this current, for medical or scientific purposes.

As already explained, when the machine is in operation there is a constant movement of electricity through the switch and its connections, from *D* to *C*, while the charge is accumulating; and the counter discharge through them, from *C* to *D*, is simultaneous with the discharge above, from *R* to *P*. When the switch is open and the cords attached, as shown, this discharge must either force its way through the kiln-dried wood, or pass out through the cords and any object connected

with their outer terminals, according to the degree of resistance offered by each path respectively. If a person, or a number of persons with hands joined, grasp the handles, the resistance will be less than through the wood, and they will feel the effects of the discharge. This discharge is regulated by the distance to which *R* and *P* are separated. With a separation of $\frac{1}{16}$ of an inch, on a large machine, the discharge is so rapid that the distinction between the impulses can scarcely be perceived; producing a faradic current smoother than can be obtained from the best batteries, while a separation of $\frac{1}{2}$ an inch produces effects which the strongest nerves cannot endure.

This current, in its milder form, cannot be distinguished from that obtained from the battery, or magneto-electric machine: but, in its more powerful effects, it is more impulsive; coming in jets, with cumulative force, like the rapid blows of a planishing hammer. In the battery current, the stronger effects show increased intensity, and a greater tendency to muscular contraction; while increase of strength in this current is due to the slower impulses giving more time for the accumulation of electric energy.

THE ELECTRIC BATH AND ELECTRIC WIND.—Charging a person on an insulated stool is one of the most common experiments in static electricity, but it has only recently come into use in medical practice; and, instead of the stool, an insulated platform, on which one or more persons can be comfortably seated, has been substituted; the treatment being known as the “Electric Bath.”

When the patient is seated, as above, the electrodes *P* and *R*, drawn out beyond sparking distance, and the

switch closed, a connection is made between the patient and the machine by a conducting cord; one end being attached to the ball surmounting one of the Leyden jars, and the other end to the chair. A similar connection is made between the opposite jar and the floor near the platform, to create a certain degree of induction, and so facilitate the process of charging, which is now done by putting the machine in operation. Very little sensation is experienced from this charge, but its effect in certain nervous diseases, which cannot be treated with the battery, such as St. Vitus dance, is said by medical men to be very soothing. In other cases, sparks are drawn from the patient with the hand or a suitable electrode, as a ball, roller, or sponge, attached to the cord from the opposite jar, and held by an insulating handle.

The electric wind is given by a point electrode, attached as above, either with or without the insulated platform. A gentle current of electrified air from the point fans the patient, producing a delightfully soothing sensation.

Electric treatment of this kind can be given only by static electricity, and its value must be determined by the medical profession, among whom it is coming into favor; being used and recommended by physicians of eminence.

GAS LIGHTING.—Lighting the gas in churches and public halls by electricity is commonly done by a battery and coil, but the Töpler machine can also be used for this purpose. With either method there must be wires connecting the generator with the chandeliers, wires connecting the chandeliers together, and also the separate burners; all arranged in one circuit and prop-

erly insulated. At each burner there is a break in the circuit, so arranged that a short spark will pass through the gas; the ends of the wire being attached to an insulator fitted to the burner.

With the battery there is a ground wire, and connection with the gas pipe to complete the circuit; but, with the machine, the circuit is made by two separate wires, connecting the chandeliers with the balls surmounting the Leyden jars. On account of the greater intensity of static electricity, these wires must be thoroughly insulated with thick rubber tubing, wherever they are liable to come in contact with the walls or gas fixtures. With these arrangements properly made, it is only necessary to close the switch, separate *P* and *R* to the full extent, turn on the gas, and put the machine in operation. The resistance of the air between *P* and *R*, being greater than the resistance of the wires and the short breaks between their terminals at the burners, the sparks take place at the burners, and the gas is lit.

As to the expense, convenience, and efficiency of this system, as compared with the battery system, only general statements can as yet be made. The first cost would probably be about the same; after which there would be no further expense with the machine, which, with proper care, should remain in good working order, for this purpose, for an indefinite term of years; while the battery requires frequent renewal of the fluid, and occasional renewal of the zinc, besides cleansing and amalgamating.

As to efficiency, the greater intensity of the spark from the machine will be evident, when we consider that a machine of very moderate size will easily produce sparks three to five inches in length, while a very

large battery and coil would be required to produce the same result. But this should be taken merely as an indication of comparative intensity; as, practically, only very short sparks are required: so that a battery and coil of medium size is generally sufficient.

A damp atmosphere does not affect the battery, while it lessens the energy of the machine; and, in unskillful hands, may interfere with its practical efficiency. But, with either system, the person in charge should have a thorough knowledge of its care and management: in which case the machine can always be kept in practical working order.

CHAPTER X.

ELECTRIC TRANSMISSION IN VACUA.

ELECTRIC TRANSMISSION IN LOW VACUA.—Let a glass tube, about thirty inches long, be provided with brass caps at each end, fitting air tight; from each of which a pointed brass rod projects inwards. And let a stop-cock be attached to one of the caps, by which the tube can be connected with an air pump, as shown in Fig. 43.

Let the tube be insulated, and the caps connected by conducting cords with the balls surmounting the Leyden jars of the Töpler machine; the sliding electrodes being separated to their full extent. When filled with air, at the ordinary atmospheric density, it will be found impossible to pass an electric charge through a tube of this length: but let it be connected with an air pump, and the air well exhausted, and a charge will easily pass through. This proves that air at the ordinary density has a much higher electric resistance than rarefied air.

But if a high degree of vacuum is produced, it will be found much more difficult to pass the charge through; which indicates that a medium, consisting of some material substance, is essential to electric existence and movement; and that if it were possible to produce an absolute vacuum, electricity could not pass through.

If the above experiment be performed in a dark room, flashes of red and violet colored light will be seen to

accompany the discharge, strongly resembling the coruscations of the aurora polaris. Hence tubes, used for this purpose, have been called *aurora* tubes.

GEISSLER TUBES —Improved tubes of this kind, called from their inventor Geissler tubes, are constructed with fine platinum wire sealed into their extremities; the points projecting inwards, and loops formed outside for the attachment of conducting cords or wires. The glass is bent into a variety of graceful curves and folds: small tubes, bent in this manner, being inclosed, for protection, in large straight ones; and thus long, frail tubes are reduced to compact, convenient forms, in which they can be safely handled, as shown in Fig. 44.

The air is exhausted from them by a mercury pump, after which they are hermetically sealed. The expansion of the fine platinum wires being very slight and nearly the same as that of the glass, is not sufficient to cause fracture, hence the vacuum produced in well-constructed tubes remains permanent for years.

Beautiful fluorescent effects are obtained by constructing such tubes of uranium glass. Similar effects are also obtained by introducing into them various solids and gases; as sulphate of quinine, fluoride of boron, fluoride of silicon, iodine, hydrogen, and nitrogen; which give certain characteristic colors, when subjected to electric action.

The effect of the discharge is greatly increased if a break be made in the connection between one end of the tube and the machine, so as to introduce a short

Fig. 43—
Vacuum
Tube.

Fig. 44—Geissler Tubes.

spark into the circuit. The electricity then accumulates and a rapid succession of brilliant discharges is the result.

The same effect can be produced by opening the switch, connecting the tube with its terminals, and slightly separating the sliding electrodes *P* and *R*.

When the spark between *P* and *R* is apparently continuous, the pulsations in the induced discharge through the tube are distinctly visible in the alternations of light and shade; proving that the discharge consists of a series of distinct impulses.

Fig. 45—Rotary Movement in High Vacua.

ELECTRIC TRANSMISSION IN HIGH VACUA.—The residual air in the ordinary Geissler tube is about $\frac{1}{1000000}$ of an atmosphere, but Crookes has produced tubes in which the residual is less than $\frac{1}{1000000}$ of an atmosphere; and the electric discharge in such tubes presents certain peculiarities not observed in ordinary vacua.

Electric action on substances inclosed in such tubes, and on the glass itself, is increased in the ratio of the increased vacuum; since those substances receive the force of energy which, in lower vacua, is expended on the air.

This increased action is shown by an increase in the light and heat developed in them, and in the attractive

force exerted on them, as shown when they are free to move.

Fig. 45 shows such a tube, having a glass railway on which is placed a roller with mica vanes, and the electrodes so placed that the upper vanes are in line between them. When an electric current passes through the tube, these vanes, being at zero potential, are attracted by the higher potential of the positive electrode, producing a rotary movement of the roller from negative to positive; the force being sufficient to move it up an incline.

Fig. 46—Rotary Movement Reversed.

Fig. 46 shows a tube in which a wheel with mica vanes is so mounted that its center is in line between the positive electrode, and the center of the negative. The negative electrode *a b* is cup-shaped, and its concave surface turned towards the positive: so that the lines of force may be brought to a focus, and concentrated on the vanes. And between its center and the wheel is placed the mica screen *c d*.

A magnet, *g*, is suspended above the tube, between

the screen and negative electrode, in such a manner that it can be turned so as to reverse the position of its poles.

By this means the electric current may be attracted or repelled, so as to pass over or under the screen. When it passes over the screen, the upper vanes are attracted towards the positive electrode, producing rotation of the wheel in accordance with such movement: but when the position of the magnet is reversed, the current is repelled and passes under the screen, and the lower vanes are attracted, reversing the rotation.

The glass in these tubes is usually of very low insulating power, much lower than that of air at the ordinary density. Hence the electric resistance in high vacua, being much greater than in the glass, electric movement takes place through the vacua and glass respectively, in the inverse ratio of the resistance of each.

Fig. 47 represents a tube in which the negative electrode consists of a half cylinder of aluminium, supported, near the center of the tube, on a small glass tube, *b*; through which a copper wire extends, connecting the aluminium with the platinum terminal below.

The ends of both electrodes come near the walls of the tube; and when the electric charge passes, its prin-

Fig. 47—Glass Illuminated

cial effect is produced on the glass, which gives a brilliant green light; the illuminated surface terminating in points near the extremities of the negative electrode.

The influence of induction on the walls of the tube, as well as the conductivity of the glass, is illustrated in Fig. 48; which represents a pear-shaped tube, having for its positive electrode an aluminium cross, *b*, placed near its broad end; the negative electrode *a* being cup-shaped as in Fig. 46. This cross is hinged at bottom to the platinum terminal; so that, by a movement of the tube, it can easily be brought to a horizontal or a vertical position.

Fig. 48—Inductive Action of Metal Screen.

When the charge is passed through the tube, the cross, when vertical, as shown in the cut, exerts a strong inductive influence on the broad end of the tube, to the left; over a space inclosed by lines extending over its edges, from the negative electrode: repelling electricity from this space, and screening it from the action of the negative electrode, which attracts electricity from the other parts of the tube, and from the surrounding air.

Hence electric action within this space is neutralized ; producing the dark shadow *c d* shown on the broad end ; while the rest of the tube is illuminated.

When the screen is thrown down a luminous cross takes the place of the dark shadow : but this higher illumination soon fades, since electric action on this space is now the same as on the rest of the tube.

If the tube be used again, after a period of rest, the shadow can be reproduced ; but is never so strong as at first. This proves that the glass has been subjected to an electric strain, which has permanently lessened its insulating power.

The illumination of the glass is due to its resistance ; just as the bright spark is due to the resistance of air at the ordinary density, and the faint glow, to the reduced resistance in vacuum. Hence, when electric action begins, after the screen is thrown down, the resistance being greater on the spot which was protected by the screen, we have the bright cross where the dark one was : but when the electric strain has so affected the relations of the molecules to each other, as to lessen the resistance, this first bright glow ceases, and the illumination is the same as in the rest of the tube.

This action on the glass, as shown in Figs. 47 and 48, is accompanied with heat as well as light ; the tube shown in Fig. 47 becoming intensely hot, at those points where the greatest electric energy is concentrated.

Fig. 49 represents a tube constructed to show this heating effect in a very striking manner. Its upper part is enlarged into a globular form : and, at the bottom, is the concave negative electrode, of aluminium, already described ; which is so placed that it brings

the lines of force to a focus on a piece of iridio-platinum, *b*, placed in the center of the globe. This, being a metal of high resistance, becomes white hot under the electric action; glowing with intense brilliancy, and finally melting.

The walls of the globe, being remote from the line between the electrodes, which is comparatively short, the glass is less affected than in the long narrow tubes: so that electric action is chiefly concentrated on the object at the center.

Fig. 49—Heat Produced in High Vacua.

Crookes attributes all these phenomena to the impact of the residual air molecules, which he designates as "*radiant matter*"; and claims that the molecules move independently of each other, and are driven with such force against the glass and other objects, as to produce the various phenomena described.

Gordon considers this theory reasonable, and elaborates it at considerable length: but it is not generally accepted; and it is believed that the explanations here given will be found more in accordance with well established electric principles.

CHAPTER XI.

ELECTRÔMETERS.

PROGRESS in every department of science is largely dependent on exact measurement, since it is only by this means that we get an accurate knowledge of relative values. The thermometer enables us to investigate the laws of heat; the barometer gives us a knowledge of atmospheric pressure, and the various matters relating to it. And in chemistry and astronomy almost every step depends on 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; the conductivity and resistance of various substances; the force of electric attraction and repulsion, the comparative energy of the various instruments used for generating and accumulating electricity; and other matters of similar importance.

But electric measurement 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 parts of the earth's surface, is subject to but slight variation.

In heat we have a force, susceptible of easy control; its movement slow, and its direction easily ascertained.

But electricity moves with the rapidity of thought; its direction is difficult to ascertain; and it defies our utmost efforts at absolute control; so that the results of measurement, by our best constructed instruments, fall short of perfect accuracy.

In static electricity less progress has been made in measurement than in other forms of electric energy, whose practical applications are more numerous.

Fig. 50—Coulomb's Torsion Balance.

The electroscope, sometimes classed with electrometers, indicates the presence of an electric charge, but cannot be said to measure it, except as such indication may show an increase or diminution of a light charge. Lane's unit jar may be considered an electrometer, and the methods of measurement by it, and by sparks from the Holtz and Töpler machines, belong to the same class: but both methods are very inaccurate, and can be used only in special cases.

COULOMB'S TORSION BALANCE.—To Coulomb is due the credit of the first efforts at accuracy in electric science; and the torsion balance, which is still extensively used, was his invention and may properly be regarded as the first electrometer.

It is represented by Fig. 50; and consists of a glass cylinder *A A*, to the top of which is attached, at the

center, a glass tube DD , to each end of which is fitted a brass collar. An enlarged section of the upper end of this tube and its attachments, representing what is known as the torsion head, is shown separately; in which it will be noticed, that the brass collar a has fitted to it a cap b with a projecting rim; on the upper surface of which is a graduated scale, of 360 equal divisions. This cap is capable of being turned horizontally, so as to bring the several divisions of the scale under a pointer c , attached to a .

In the center of b is a close fitting brass rod d , with a broad head by which it can be turned, when b is held firmly; or the rod may be allowed to turn with b . Attached to this rod is a fine wire, which sustains, at its lower extremity, a horizontal shellac rod f , carrying at one end a small gilt ball g . Opposite this ball, on the cylinder AA , is a graduated scale aa , having 360 divisions, to correspond to those of the upper scale. Opposite the zero of this scale is a gilt ball g' , of the same size as the other gilt ball, and supported by a shellac rod f'' , by which the ball can be introduced through an opening in the top of AA .

The instrument is supported on a base, having leveling screws; and the air, in the interior, kept dry with chloride of calcium.

To use this instrument, the cap b is turned till the zero of the upper scale is brought under the pointer c . The rod d is then turned till the movable ball g just touches the fixed ball g' , without torsion of the wire. The zeros of the two scales will then be practically in the same vertical plane.

The fixed ball g' is then taken out, electrified, and replaced as before, in contact with the movable ball g .

Both being the same size, the charge is equally divided between them; and, being at the same potential, the movable ball g is repelled to a distance indicated by the number on the lower scale: at which point the force of repulsion is balanced by the torsion of the wire.

The cap b is then turned in opposition to the repulsion, so as to bring the ball g nearer to g' ; the distance being indicated on the upper scale. The torsion of the wire is thus increased, and repulsion again balanced by torsion in the new position.

It is known that the force of torsion is proportional to the angle of torsion: and since this force has to be increased to oppose the increase of repulsion, as the balls are brought closer, the point to be determined is the ratio of increase of force, as compared with the reduction of distance between the balls; which is done by comparing the distances from zero indicated on the upper and lower scales.

The following is one of Coulomb's experiments for this purpose: The first distance to which the movable ball g was repelled being 36° , it was found necessary, in order to reduce this distance to 18° , to turn the cap b through 126° ; and to reduce the distance to $8\frac{1}{2}^\circ$ required an additional rotation of the cap through 441° .

The distances 36° , 18° , and $8\frac{1}{2}^\circ$ are to each other, practically, in the ratio of 1, $\frac{1}{2}$, and $\frac{1}{4}$; and the forces of repulsion at these points were balanced by torsions of 36° , of $126^\circ + 18^\circ = 144^\circ$, and of $441^\circ + 126^\circ + 8\frac{1}{2}^\circ = 575\frac{1}{2}^\circ$, respectively.

Now since $144 = 4 \times 36$, and $575\frac{1}{2}$ (practically 576) $= 16 \times 36$, it will be seen that as the distance between the balls is divided by 2 or by 4, the force of repulsion is multiplied by 4 or by 16; and thus Coulomb proved

that *electric repulsion varies inversely as the square of the distance*.

INACCURACY OF THE TORSION BALANCE.—In the use of this instrument, as above, the arc is assumed as the distance between the balls, while the actual distance is the chord of the arc; but since these distances are in the same proportion, the accuracy of the results is not affected.

It is also assumed that the arm of the lever, by which repulsion produces torsion, is the distance from the center of motion to the center of the ball g . But this is true only when the balls are in contact. In every other position, this arm is represented by a perpendicular from the center, on the chord which cuts the centers of the two balls: and as the ball g moves round, and the chord increases in length, this perpendicular decreases; and vanishes when the chord equals the diameter.

Fig. 51—Arm and Angle of Repulsion Illustrated.

This is shown in Fig. 51, where b represents the first position of the balls, when the arm equals ab : but when g moves round to c , the line af represents the arm; and when it moves to d , the short line am represents the arm; and at n the arm vanishes.

This may be made more plain, by considering that the ball g is moving under the influence of two forces, electric repulsion, and the rigidity of the shellac rod, by which it is held at a fixed distance from the center.

When motion begins, at *b*, these forces act at right angles to each other but as the ball moves round, the angle of repulsion constantly decreases; being represented at *c*, by the angle *a b c*; and at *d*, by the angle *a b d*; and vanishing at *n*, where the two forces are in direct opposition.

In this position the force of repulsion opposes further movement: for, as it radiates equally in every direction from the two balls, its force on opposite sides of *n* is equal. But since, in the experiment given, the greatest angle was 36° , which is only one-fifth of the semi-circle, the error is not sufficient to affect the result seriously.

Another inaccuracy results from lack of rigidity in the fine wire, which causes it to deviate slightly from a true vertical, under the influence of repulsion; moving its lower extremity out of the center.

There is also a slight inaccuracy resulting from the force of repulsion being estimated from the centers of the balls, instead of from their nearest points.

It is also assumed that electric repulsion remains constant during the experiment: which would not be strictly true; since there is a continual reduction of energy, from causes already explained, which would produce serious error, if the experiment were of long duration.

Since each ball becomes a center of electric radiation, it is evident that the lines of force cut by each represent but a very small part of the entire repulsive energy. But since the balls are of equal size and equal potential, it may be assumed that the proportion between the energy actually measured, and the entire energy, is the same in each ball. But an instrument embracing all the lines of force would evidently be more reliable.

These inaccuracies doubtless account for the slight error observed in Coulomb's experiment, and tend to confirm the correctness of his results by showing sufficient cause for the error.

ATTRACTED-DISC ELECTROMETERS.—Sir W. Snow Harris was the first to construct an electrometer on the attracted-disc principle. His instrument consisted of a scale beam, carrying at one end a pan for the weights, balanced at the other end by an insulated metal disc, suspended horizontally over a similar fixed, insulated disc.

An electric charge being given to the lower disc, the force of attraction between it and the upper disc was measured by weights placed in the scale pan.

The rapid loss of charge, from the edge of the electrified disc, was the chief objection to this instrument. But the principle has been adopted, and the construction improved by Sir William Thomson, whose instrument, shown by Fig. 52, is described as follows:—

THOMSON'S ABSOLUTE ELECTROMETER.—This instrument consists of two distinct parts; one for testing and maintaining a certain constant auxiliary potential V , and the other for determining, in absolute measure, the difference between the potentials of any two given conductors. The first of these parts embraced a *Leyden jar*, forming the case of the instrument, an *idiostatic gauge*, and a *replenisher E*.

The Leyden jar is a glass cylinder, closed at top and bottom by metal plates; and coated, inside and out, with tin-foil, in which openings are left for viewing the internal parts; and an uncoated surface, for insulation, left at the top and bottom, between the inner coating and the metal plates.

The idiostatic gauge will be understood from Fig.

Fig. 52—Thomson's Absolute Electrometer.

53. A small aluminium plate P is fitted to a square hole in the metal plate G , like a trap-door, without touching the edges. To one side of P is attached an arm h , of the same material, enlarged at its junction with P , and bent, so that when the surfaces of P and G are in the same plane, the arm is elevated a little above G , and is parallel with it.

A platinum wire f stretched between two supports, attached to G , passes through the enlarged part of the arm h , over a slight projection; supporting P , and, by its torsion, regulating its movements. At the outer end of the arm is a fork

F ; and between its prongs is a little white enameled standard, attached to G ; having, on its outer face, two black dots, close together, and in the same vertical line. A black

Fig. 53—The Idiostatic Gauge.

hair, stretched across the fork, and viewed through the lens l , moves up and down in front of the dots; and comes exactly between them, when the surfaces of P and G are in the same plane. This is called the sighted position.

Under the plate G is seen, in Fig. 52, a circular metal plate F , supported on a metal rod, attached to the metal plate A , which is in contact with the inner coating of the Leyden jar; so that A and F are always at the same potential V , as this coating. The distance between F and G is so regulated, that when the potential of F is V , its attraction for the plate P overcomes the torsion of the platinum wire, and keeps P in the

sighted position: and, in this way, the constancy of the potential V is tested.

This constancy of potential is maintained by the *replenisher* seen at E , which is practically a small Töpler machine; and is shown separately in Fig. 54. A and B are two insulated metal inductors, to which are attached two receiver springs a and b . C and D are two contact springs, in electric connection with each other, but insulated from the other parts.

Fig. 54—The Replenisher.

P and Q are two metal carriers, attached to an ebonite cross-piece, through which passes the ebonite axis T , which can be rotated by the milled head E : so that the carriers P and Q , revolving inside the inductors A and B , shall successively touch the springs a , D , b , C .

When the replenisher is in its place, as shown in Fig. 52, the inductor A is put in electric connection with the disc A ; which is supported in connection with the inner coating of the Leyden jar: while the inductor B , being in contact with the cover, is in electric connection with the outer coating. And since the replenisher operates on the principle of the Töpler machine, already described, its rotation, either direct or reversed, will raise or lower the potential of the jar: and so keep the potential of the plate A , and of the idiostatic gauge, connected with it, at the constant potential V , as shown by the gauge.

The second part of the electrometer consists of the apparatus for expressing differences of potential, between conductors, in absolute measure. The metal plate *A*, called the *guard plate*, has, at its center, a circular opening about $1\frac{3}{4}$ inches in diameter, to which is fitted the disc *C*; which just fills it without touching the edges; and is made of thin aluminium, flat and smooth on its under side, but strengthened by a rim, and radial arms, on its upper side. It is supported by three light steel springs, shaped somewhat like tuning-forks, and placed horizontally, at equal distances apart; one of which is shown at *S*. The lower end of each is attached to the center of *C*, and the upper end to a brass socket, which is cemented to the lower end of a glass rod, shown at *I*; which insulates it from the metal rod above; to the lower end of which the glass rod is attached. And the metal rod is moved vertically in guides by the micrometer screw *M*; the movements being registered by the scale *G*, and the graduated disc *D*.

To the center of the disc *C* is attached a fine hair: in front of which a lens, *H*, is so placed as to form, at its conjugate focus, near the surface of the jar, an image of the hair; which may be viewed through the eye-piece at *L*. This image is seen exactly between the points of two screws *K*, when the lower surfaces of the disc *C*, and guard plate *A*, are in the same plane: which is called the sighted position.

On a support below *A*, is the metal disc *B*, known as the *attracting disc*; insulated from the jar, and movable vertically by the micrometer screw *M'*; the movements being registered by the scale *R*, and the graduated disc *T*. It is connected with the electrode *N*, by

which it can be put in electric connection with bodies whose potential is to be tested.

The attracted plates P and C are really movable centers of the guard plates G and A ; and since loss of charge, from radiation and otherwise, affects chiefly the outer edges, the small centers are practically unaffected by such loss. Hence the large discs G and A are appropriately called guard plates.

MODE OF USING THE ABSOLUTE ELECTROMETER.—The plates are first brought to zero potential, by putting them, for an instant, in electric connection, by the electrode N , connecting with B , and a wire connecting with A through the cover. The disc C is then brought to its sighted position by the micrometer M , and the reading noted. A known weight, w , is then placed upon it so as to depress it below the level of the guard plate A ; and M is turned till C is again raised to its sighted position: the reading is noted, and the weight removed.

The Leyden jar is then charged to potential V , as determined by the idiostatic gauge, and kept constant by the replenisher, during the experiment. The disc B is now put into connection with the outside coating by the electrode N ; and the micrometer M' turned till the attraction of B on the disc C brings it again to its sighted position. Hence the attraction of B is known to be equal to the weight w . This reading being noted, B is insulated, and the bodies, the difference of whose potentials x and z is required, are successively put into contact with B through N . The distances d and h through which B has to be moved to bring the disc C , in each case, to its sighted position, are noted, and the difference of potential can then be calculated.

FORMULÆ FOR CHARGED SURFACES. — With a

given charge, the electric energy at any point on a conductor, called its *surface density*, is in proportion to its surface area. Let ρ represent the surface density, then the electric force, exerted by a charged conductor on a point near it, equals ρ multiplied by the surface area.

On a sphere the surface equals the square of its radius multiplied by 4×3.14159 . If $3.14159 = \pi$, and radius $= 1$, we have $1^2 \times 4\pi = 4\pi$. Hence the force exerted by a charged sphere on a point near it equals $4\pi\rho$; and the force exerted by a charged hemispherical surface equals $2\pi\rho$.

The hemispherical surface may be considered as made up of the bases of an infinite number of small cones, having their apexes at the center. Hence each base subtends a solid angle: and lines of force, extending from surface to center, are everywhere normal to the surface.

Now if we conceive a plane surface applied to the hemispherical surface, and these cones extended to meet it; we find that the lines of force, extending from these bases, are oblique to the plane surface. Hence each one can be resolved into two components, one normal to the plane, and the other acting along it. But since there are an infinite number of these cones, the lines of force from whose bases may all be resolved in this way; the components along the plane, all around, neutralize each other, leaving only the normal components; whose force equals the sum of all the solid angles multiplied by the surface density, which, as we have seen, equals $2\pi\rho$. Hence the expression is the same for a plane or a hemispherical surface.

APPLICATION OF FORMULÆ TO MEASUREMENTS BY ELECTROMETER.—When there are two discs, at

different potentials, near each other, as A and B in the electrometer, the attraction of each for the other is equal; the air being the dielectric between them. Hence the force, exerted at any point between them, equals the force on *both* surfaces, represented by $4\pi\varrho$; and tends to draw the movable disc C towards B . But this force is also equal to the difference of potential, divided by the distance between the discs. Hence when x represents difference of potential, and d the distance, the resultant force, at any point, equals $\frac{x}{d}$. Hence $4\pi\varrho = \frac{x}{d}$, and $\varrho = \frac{x}{4\pi d}$.

Now if the surface of the movable disc C be represented by s , its attractive force will equal $s\varrho$: hence the total attractive force equals $2\pi\varrho \times s\varrho = 2\pi s\varrho^2$. And substituting for ϱ its value, $\frac{x}{4\pi d}$, we have

$$2\pi s \left(\frac{x}{4\pi d} \right)^2 = 2\pi s \frac{x^2}{16\pi^2 d^2} = \frac{s x^2}{8\pi d^2}.$$

Now since the attractive force equals the weight w , multiplied by the acceleration produced by gravity, represented by g , we have $wg = \frac{s x^2}{8\pi d^2}$: therefore $x = d \sqrt{\frac{8\pi w g}{s}}$ (1), which expresses x in absolute measure. But x represents the potential of the first body tested by the electrometer.

By a similar process the potential, z , of the second body is expressed by the equation, $z = h \sqrt{\frac{8\pi w g}{s}}$ (2). Subtracting (2) from (1), we have $x - z = (d - h) \sqrt{\frac{8\pi w g}{s}}$.

By substituting figures for the letters in the second member of this equation, the difference of potential, of any two bodies we wish to test, may be expressed arithmetically.

The expression $\sqrt{\frac{8 \pi w g}{s}}$ is constant; since it represents the attraction of the disc B for C , when the Leyden jar is at the constant potential, V : while the expression $(d-h)$ is variable; representing the difference of distance, required by the variable difference of potential, expressed by $x-z$.

THOMSON'S QUADRANT ELECTROMETER.—This instrument, invented by Sir William Thomson, is highly esteemed for its great sensitiveness. It is represented by Fig. 55, and consists of a frame supporting a Leyden jar, which resembles an inverted glass shade, with a brass cover, to which the principal parts are attached.

These consist of the idiostatic gauge and replenisher, already described, and the quadrants and needle, and parts connected with them.

The jar contains strong sulphuric acid: which forms the inner coating, keeps the interior free from moisture, and forms a perfect connection with the needle, without friction. The outer coating consists of strips of tin-foil, connected with the cover and supporting frame. The upper part of the jar incloses the quadrants and needle; protecting the needle from currents of air, and permitting its movements to be seen.

Fig. 56 is an enlarged view of the needle and quadrants. The needle is a thin, flat piece of aluminium, shaped like a figure 8; represented by the dotted lines in Fig. 56; and seen edgewise in its place at u , in Fig. 55. Through its center passes a piece of stout platinum wire to which it is attached, and which terminates

above in a small, T-shaped piece of metal: to which are attached, at the extremities of the cross piece, two fibers of unspun silk; by which the needle is suspended

Fig. 55—Thomson's Quadrant Electrometer.

from a projecting arm, supported, in the upper part of the instrument, on a vertical glass rod. When the needle is at rest, in the fixed position between the quadrants, as shown in Fig. 56, the silk fibers hang parallel to each other, and the cross piece, below, is

then parallel to the projecting arm above. But in any other position, each fiber is at an angle with its vertical position, and the needle slightly elevated: consequently the force of gravity tends constantly to turn the needle, without friction, back to its fixed position. This mode of suspension is termed *bifilar*.

A platinum weight, suspended in the sulphuric acid by a fine platinum wire, from the lower end of the stiff wire below the needle, keeps the needle in position, and in contact with the inner coating.

The wire, above and below the needle, is inclosed in fixed guard tubes; the lower one shown at *w*: which screen it from external electric influence; and furnish a connection, by which the charge is given to the inner coating.

Fig. 56—Quadrants and Needle.

The needle is inclosed within four brass quadrants: which, if joined, would form a circular box. They are separated from each other, and from the needle, as shown in Fig. 56: and opposite pairs, *A* and *A'*, *B* and *B'*, are connected by fine wires; and all supported at the same level; and insulated, by glass rods attached to the cover.

Three of them are permanently attached, but the fourth can be moved in and out horizontally; guides, and a spring and counteracting screw, being arranged to keep it in position, and regulate its movement.

Above the needle, and attached to its supporting wire, is a small concave mirror *t*; by which a ray of light is reflected on a scale, placed in front of it, at a

distance of about 36 inches. This scale is shown in Fig. 57. Behind it is a lamp, the light from which comes through a vertical slit in a screen: above which is a horizontal screen, which cuts off the direct rays from below; while the angle of reflection brings the ray from the mirror directly on the scale, where it appears as a small spot of light. Another screen, placed at an angle, cuts off the direct rays from above.

As the mirror turns with the needle, the reflected ray becomes a long pointer; moving without friction: by which the slightest movement of the needle is indicated on the scale.

Fig. 57—Scale, Lamp, and Screen.

In the instruments first constructed, the needle was suspended by a single fiber of silk; and a small magnet attached to the back of the mirror: which, by the attraction between it and a large magnet, placed outside the jar, as shown in Fig. 55, controlled and limited the movements of the needle; the attraction of the magnets tending constantly to bring it back to its fixed position, where the spot of light rests on the zero of the scale. But the bifilar suspension is now preferred; rendering the use of magnets unnecessary.

At *l* and *m*, Fig. 55, are seen the *chief electrodes*; used to connect the opposite pairs of quadrants with bodies whose potential is to be tested: and at *p* is the

charging electrode, used to connect the replenisher with the inner coating of the Leyden jar. One pair of quadrants, $A A'$, Fig. 56, is connected with the electrode l , and the other pair, $B B'$, with the electrode m .

MODE OF USING THE QUADRANT ELECTROMETER.

—The Leyden jar is connected with the replenisher by the electrode p , and charged to a certain constant potential, V , as indicated by the gauge; and its constancy maintained during the experiment: and the needle, being connected with its inner coating, has therefore the same constant potential V .

By means of the electrodes l and m , a connection is then made between the opposite pairs of quadrants, and any two bodies whose difference of potential is required; one of which is usually the earth. Suppose the earth connection to be made with the electrode m ; then, if the potential of the other body is higher than that of the earth, the needle will move round from the higher to the lower potential; that is, from $A A'$ to $B B'$: but if it is lower, the movement will be from $B B'$ to $A A'$: and the difference of potential will be indicated on the scale by the movement of the spot of light, to the right or left from zero; and may be considered practically correct, within certain limits. In this way the required potentials are compared with the constant potential V ; and the results determined in absolute measure.

In the Helmholtz quadrant electrometer the quadrants are maintained at the constant potential; and the bodies whose potential is required are connected with the needle.

There are various styles of Thomson's electrometers: both of the attracted-disc and quadrant instruments. Some of them are portable, and much simpler than

those already described; the replenisher, gauge, and Leyden jar, being omitted; also the bifilar attachment in the quadrant instrument; the movements of the needle being controlled by the torsion of a fine wire. And, in the attracted-disc electrometer, the position of the discs is sometimes reversed; the attracting disc being placed above, in the portable style.

CHAPTER XII.

THE ELECTRICITY OF THE EARTH AND ATMOSPHERE.

POTENTIAL AND EARTH CURRENTS.

TERRESTRIAL and atmospheric electricity are so intimately related, that to obtain a correct knowledge of either requires the consideration of its relations to the other.

Viewing electricity as a universal property of matter, its existence in the earth and atmosphere follows as a necessary consequence. Hence, we are to study its phenomena in this connection, rather than to account for its origin. These phenomena pertain chiefly to difference of potential between different parts of the earth's surface; different parts of the atmosphere; and between the earth's surface and the atmosphere.

This difference of potential results from various causes. We have already seen how difference of potential may be produced, artificially, by various instruments, which are combinations of different substances, having different degrees of electric resistance and conductivity. By similar methods nature, on a grand scale, produces results of which ours are but feeble imitations.

ILLUSTRATIONS FROM THE THERMOPILE.—In the *thermopile* we have an illustration of the method by which difference of potential is produced by heat. This

instrument is a combination of metal bars, whose conductivity for heat and electricity varies greatly. A number of these bars, arranged in compact form, and properly insulated, are soldered together in an alternating series: so that a current of electricity, passing through them, has to pass from one metal to the other. They are folded together, and mounted in such a manner, that heat may be applied to one set of junctions; while the opposite, alternate set, is cooled.

In this way, instruments are constructed, in which a very slight difference of temperature, between the opposite sets of junctions, creates a perceptible difference of electric potential: and powerful batteries are constructed in the same manner.

The earth may be regarded as an immense battery of this kind; being composed of heterogeneous materials, whose conductivity for heat and electricity varies greatly: and which are subjected to great extremes of temperature, at opposite junctions, fulfilling exactly the conditions of the thermopile.

The ocean, a vast, homogeneous conductor, is separated into different parts by the great continents; whose conductivity differs from it greatly: the five great divisions of the ocean, and the two continents, constituting an alternating series of conductors, of different conductivities.

The surface of the continents, composed of rock and soil, of lakes, rivers, and sandy deserts, presents a great diversity of material, of widely different conductivity.

In the torrid and frigid zones, we have the opposite extremes of temperature; which, in the thermo-electric battery, are produced by exposing one set of junctions to the heat of a lamp furnace; while the opposite set is

cooled with ice. Similarly also in the diurnal revolution of the earth, opposite sides are subjected daily to a constantly changing temperature. And, in its annual revolution, we have the same result in the changing seasons; which also produce great changes in the conducting character of the surface; from the frozen, snow-clad surface of winter, to the verdure-clad surface of summer.

DIURNAL AND SEASONAL VARIATION.—The change of electric potential produced by these causes in the earth, induces the opposite potential in the atmosphere; which, by its lower strata, is insulated from it. Hence, in observations made on the potential of the earth and atmosphere, we find, as we should be led to expect, daily maxima and minima potential, and also seasonal maxima and minima.

In several series of observations, made by different observers in Europe, both on the continent and in the British Isles, these maxima and minima were carefully noted: and it was found, that, in winter, the daily maxima occur at about 10 A. M. and 7 P. M.; in summer at about 8 A. M. and 10 P. M.; and in spring and autumn, at about 9 A. M. and 9 P. M. The daily minima occur, in summer, at about 3 P. M., and midnight; but the daily winter minima are not given with sufficient definiteness to be reliable.

From this we see, that the daily maxima, occurring soon after sunrise and sunset, correspond to the hours of greatest change of temperature; while the daily minima occur at the hours when temperature is most constant.

The seasonal maximum occurs in winter, and the seasonal minimum in summer: the maximum about

January, and the minimum in May and June. They are doubtless due, in part, to the different conductivity of the earth's surface in summer and winter, as already mentioned; and also to the dry winter atmosphere, when atmospheric insulation is high, as compared with the damp atmosphere of spring and early summer, when it is low; the greatest minimum occurring in the months when our atmosphere, in the north temperate zone, is most heavily laden with vapor. At this season the earth is covered with green, succulent herbage; wet with frequent showers, and laden at night with heavy dews; forming a conducting surface, which offers but slight resistance to electric transmission.

Towards the close of summer, the grain ripens, the showers become less frequent, the dews lighter, and a vast expanse of dry straw and stubble, with a parched soil beneath it, offering high electric resistance, takes the place of the former conducting surface. As fall advances, and the grass becomes dry and withered, and the trees shed their leaves, there is a constant increase of this surface resistance, and a corresponding increase of electric potential, till the winter maximum is reached.

While this difference of conductivity in the land surface is taking place, the conductivity of the water surface remains practically constant: hence the period of minimum potential corresponds to that in which the difference of conductivity, between the land and water surfaces, is least; while the period of maximum potential corresponds to that in which it is greatest; pointing clearly to this difference as a probable cause.

In addition to the changes of electric potential, *induced* in the atmosphere by these changes in the elec-

tric condition of the earth's surface, its electricity is doubtless affected, *directly*, by conditions similar to those which affect the earth's electricity.

In its combination of dry air and watery vapor; the one, an insulator, and the other, a conductor; separate parts heated and cooled alternately, twice in twenty-four hours, we have thermo-electric conditions similar to those already noticed in the earth's surface; though the resulting electric disturbance is, perhaps, less intense, as the composition of the atmosphere is nearly uniform, while that of the earth's surface presents great diversity.

DIFFERENCE OF POTENTIAL BETWEEN ATMOSPHERIC STRATA.—Another cause of atmospheric electric disturbance is found in the great difference of electric resistance between the upper and lower atmospheric strata; caused by the density below and rarity above. This resistance makes the dense lower stratum, where most of our observations are made, an excellent insulator; while the rarity of higher strata facilitates electric transmission; a constant decrease of resistance taking place, from the lower to the higher, till a point is reached, where it is reduced to that of the ordinary Geissler tube; while, in still higher strata, the resistance increases, on account of the extreme rarity of the air: which equals, and finally exceeds, that of the best vacuum tubes.

The existence of a corresponding difference of electric potential has been proved by numerous experiments; among which may be noted the following:—

From an elevated position, a metal-pointed arrow was shot upward to a vertical height of 250 feet: a conducting cord, connected with it, and properly insulated,

communicated with an electroscope at its lower extremity. As the arrow rose, the electroscope showed a steadily increasing difference of potential, till the indications equaled the full capacity of the instrument.

The arrow was then shot horizontally, at an elevation of about three feet, but no change of potential was indicated; proving that the indications resulted from a difference of potential existing in the atmosphere, and were not due to the friction of the arrow in passing through the air.

The difference of potential, in this experiment, was between the earth and atmosphere: but the following experiment was entirely independent of the earth. During a balloon ascent, a conductor, 170 feet in length, was lowered into the air; a ball being attached to its lower end, and its upper end connected with an electroscope. The indications showed a marked difference of potential between the upper and lower strata.

As the balloon moved with the wind, the friction between the ball and the air could not have been sufficient to affect the electroscope perceptibly; so that, in this instance, as in the former, the indications of the instrument must be attributed to a difference of potential existing in the atmosphere.

The series of observations already referred to, and numerous others of a similar character, prove that the potential of the atmosphere is almost invariably positive with reference to that of the earth.

THE ATMOSPHERE AS A LEYDEN JAR.—It is evident that we have, in the atmosphere and on the earth's surface, the same conditions which exist in the Leyden jar—two conducting surfaces insulated by a dielectric; the stratum of least resistance forming the upper con-

ducting surface; the earth's surface, the lower one; and the dense lower stratum, the dielectric. And, as in the Leyden jar, any change of potential in either surface produces the opposite electric condition in the other surface.

The upper surface, being insulated, corresponds to the inner coating; and the lower uninsulated surface, to the outer coating. But since those surfaces are of vast extent, any limited area of upper surface would be connected with a conducting surface at its outer edges; through which connection electricity would be repelled from this area, or attracted to it, as the potential of the surface below it had a greater or less intensity. But the earth connection, of the lower surface, would be exactly the same as that of the outer coating of the Leyden jar.

We live and move on the outer coating of this Leyden jar; on a surface practically equipotential within limited areas; and hence do not perceive electric action taking place, no matter how highly charged the jar may be, except when the tension becomes strong enough to overcome the resistance of the dielectric, or to render prominent or visible the action on either side of it.

This surface then, which we call neutral, is really a charged surface; but, like the outer coating of a charged Leyden jar, quiescent, till brought into action by connection with the inner coating, or by induction between the two.

ASCENDING AND DESCENDING CURRENTS.—We have seen how air currents are produced by the action of an electric machine, and how light bodies vibrate between electrodes connected with opposite surfaces of

a charged Leyden jar. Now since a constant difference of potential is proved to exist between the earth's surface and the atmosphere, and between upper and lower atmospheric strata, we must conclude that ascending and descending currents result from this difference: and that the clouds, and the invisible vapor diffused through the air, are, like the air, subject to this constant electric movement. But, there being also a horizontal movement, due to the winds, the resultant of the two movements is a series of curves, ascending and descending, as the body of air and vapor moves over areas of high or low potential.

The air and vapor in contact with the earth, becoming electrified to the same potential as the earth's surface, are repelled, and attracted upward by the force resulting from difference of potential in the stratum of least resistance above. Similarly the air and vapor above are repelled, and attracted downward in consequence of the difference of potential below.

The morning and evening maxima, occurring at opposite points in the rational horizon, show that two electric waves traverse the surface daily from east to west, as the earth revolves from west to east. And, at points about equally distant from these waves, follow the two daily minima. During the maxima the ascending and descending currents must acquire a great increase, both in volume and in acceleration of movement: while the minima, preceding and following, create horizontal movements between the areas of high and low potential; producing resultant curves, similar to those due to the winds, but recurring in regular succession. In fact these currents are themselves electric winds.

The rarefying of the air from heat, at the time of the morning maximum, must increase and accelerate the ascending current, while its condensation from cold, at the evening maximum, similarly affects the descending current; gravity in each case supplementing electric force.

COSMIC ELECTRIC INFLUENCE. — Assuming that electricity is a universal force, acting through matter in different forms, as a universal medium, it follows that electric induction is universal. Hence induction between our planet and the other members of the solar system, especially the sun and moon, must affect the electric condition of the earth and atmosphere.

It is considered a well established principle, that the tides are due to the attraction of the sun and moon, attributed to gravity. But the daily electric maxima and minima indicate that there are electric tides, coincident with the ocean tides, due to the electric induction of the sun and moon: that an electric impulse follows the earth's movement, as different portions of its surface are successively exposed to this influence during its daily rotation, producing electric currents in both the land and water surface; and perhaps also tidal waves in the ocean and atmosphere.

We have seen that when a charged sphere is placed near the end of a cylinder, or of the longer axis of a spheroid, the electricity of the cylinder or spheroid is either repelled or attracted by induction, according as the potential of the sphere is positive or negative, with reference to that of the other body; and that this effect is intensified when two charged spheres, at different potentials, are placed at opposite ends of the cylinder, or longer axis of the spheroid. If both are placed at the same end, the inductive effect is a mean between

the two effects. But if one be placed opposite the center of the cylinder or spheroid, so that its action is at right angles to that of the other, the intensity of action at the ends is diminished.

In the sun, moon, and earth, these conditions are exactly fulfilled as to shape and position; and, probably also, as to difference of potential. The earth is an oblate spheroid, whose longer axis lies east and west; pointing nearly to the apparent path of the sun and moon. Hence at the full moon, the new moon, and the quarters, we must have the same inductive effects as in the experiment with the spheroid and the two spheres. The earth, at full moon, is between the sun and moon, and receives the highest inductive effect. At new moon they are on the same side of it, and nearly in line, and their effect, if at different potentials, is lessened: while, at the quarters, when the induction from each is at right angles to that of the other, it is at its minimum. Hence we should expect to find, as in the ocean tides, electric neap and spring, ebb and flood tides.

Very little is known of the relative inductive influence of the sun and moon on the earth. Judging from the analogy of the ocean tides, we might infer that the induction of the moon is greatly in excess of that of the sun. But in estimating effects produced by gravity, the two principal factors are mass and square of distance; whereas, in estimating inductive electric effects, the various agencies by which electricity is generated must also be taken into account.

The nearness of the moon to the earth causes its effect on the ocean tides to be much greater than that of the sun, though its mass, as compared with the mass of the sun, is only as 1 to 26,400,000. But, in consid-

ering the electric influence of the two bodies, we find that the lunar surface is that of a dead world, absolutely quiescent, so far as we know; while the solar surface, to a great depth, is in a state of the most violent agitation. From which we must infer a great difference of electric potential in favor of the sun. And observation indicates that this state of agitation affects the earth's electricity; while we have no observations of electric effects produced by the moon.

Certain electric phenomena on the earth are found to coincide with certain solar phenomena. These consist in violent oscillations of the magnetic needle during prominent solar disturbances, indicated by the sun spots. And it is found that the periods of maximum solar disturbance, which occur once in eleven years, are noted for corresponding maxima in those perturbations of the magnetic needle.

To make this clear, it should be stated that magnetism is produced, artificially, by the circulation of an electric current around a conductor capable of being magnetized, at right angles to its length; as by a current circulating in a coil of wire, round a bar of iron or steel. And, conversely, a magnet generates an electric current in such a coil.

It is known that the earth is a great natural magnet; having north and south magnetic poles, which exercise a directive force on the magnetic needle; and it seems highly probable, that its magnetism is the result of electric waves, or impulses, circulating round it from east to west as has been shown; giving rise to electric currents; and due to difference of temperature, and to solar and lunar influences: and that the perturbations of the magnetic needle, coincident with solar disturb-

ances, are the result of corresponding disturbances in these electric movements.

OBSERVATIONS ON TELEGRAPH LINES.—The telegraph affords special facilities for observing many of the phenomena pertaining to terrestrial and atmospheric electricity, by means of its long lines of nearly uniform conductivity, insulated in the air, having earth connections at points remote from each other, and extending, in the United States, chiefly, either at right angles to the magnetic meridian, or parallel with it.

These facts have been recognized; and, within the last five years, observations have been made, on a limited scale, in the United States, and in Europe. These observations have been somewhat desultory and local; no general, extended, well established system having yet been instituted.

During the fall and winter of 1883–84, a series of observations was made on a line belonging to the Postal Telegraph Co.; extending, at first, from New York City to Meadville, Pa.; 509 miles by wire, 325 direct; but subsequently completed to Chicago; 1058 miles by wire, 725 direct. The observations from Oct. 18 to Nov. 20, 1883, were between New York and Meadville; and the subsequent observations, which were continued during November and December, 1883, and part of February, 1884, were between New York and Chicago.

The line consisted of a large copper wire having a steel core; thus combining conductivity and strength; and the object of the observations was to ascertain the relations of the electric current to difference of temperature. They were made daily, at both ends of the line, at the hours when it was least occupied with other business, 8 to 8.30 A.M., 5 to 5.30 and 11 to 11 30 P.M.

The line being disconnected from the batteries, and connected with the earth at both ends, the current was obtained from the earth alone, independent of any artificial source: and its strength and direction, as indicated by the galvanometer, were noted, and also the temperature.

It was found, that the general direction of the current was from a region of high to one of low temperature, though frequent reversals of current were observed. And as the east, from longer exposure to the sun's heat, would have a higher temperature than the west, at the time of the morning observation, the prevailing current, at this hour, was found to be from east to west. As these conditions of temperature would be reversed in the evening, the observations at that hour showed a corresponding reversal, and a prevailing west to east current. While the observations near midnight, when another reversal of temperature is at hand, showed that the current then was fluctuating and uncertain.

The deflection of the galvanometer needle varied from 0 to 57° ; the morning average being 11.4° , the evening average 14.3° , the average near midnight 7.3° , and the general average 11° . The difference of temperature, between the points of observation, varied from 0 to 37° ; the morning average being 14.5° , the evening average 9.5° , the average near midnight 10.3° , and the general average 11.4° .

When the earth connection was severed, at either station, the current was reduced to a minimum; corresponding to the probable leakage along the line; proving that it was an earth current, and not an atmospheric current.

If a similar east and west line were extended round

the globe, we may reasonably infer that similar results would be observed on every part of it; and hence, that east and west currents are constantly traversing the earth, as it revolves from west to east.

This will be more fully understood, when we consider, that, during the diurnal revolution of the earth, the sun occupies practically a fixed position with reference to it: so that from the earth's heated hemisphere, electric currents are constantly flowing, from a central point where the sun's rays are vertical, in opposite directions, towards a point within the cooler hemisphere, opposite to the sun.

But the diurnal revolution of the earth brings any limited area of its surface, surrounding an observer, alternately into each of these currents. So that, while they have a fixed direction with reference to the sun, and to the earth, as a whole; they become, alternately, east or west currents, with reference to such an area.

From noon to midnight this area would be in the west to east current; and, from midnight to noon, in the east to west current; an equatorial point, on the observer's meridian, passing the point from which the currents diverge, at noon; and reaching the point towards which they converge, at midnight.

At both these hours, the temperature, at equally distant points in the observer's latitude, reaching from his position, east and west to the sensible horizon, is nearly the same: and the noon and midnight minima of electric potential are the result.

At sunset and sunrise the temperature on similar quadrants of the observer's latitude, east and west of his position, attains its maximum difference; and the evening and morning maxima of electric potential occur.

It will be observed that while the observer's position reaches the point of highest temperature at noon, the point of lowest temperature is reached at sunrise. For the heating of any given area begins at sunrise, increases till noon, as the sun's rays become more vertical; and declines from that hour till sunset, as the rays become less vertical; while the cooling is constant from sunset to sunrise. So that the morning difference of temperature, between east and west regions, is greater than the evening difference; and we should expect to find a corresponding increase of electric potential, at the morning maximum.

But the series of telegraphic observations given shows the reverse; which may result from the fact that the line on which the observations were made, has the Atlantic ocean at its eastern terminus, and the interior of the continent at its western. And, as change of temperature is much slower on a water surface than on a land surface, the difference of temperature between the Atlantic on the east, receiving the sun's rays first, and the interior on the west, would be less in the morning than in the evening, when these relative positions are reversed.

As the distance between heated and cooled regions alternately increases or diminishes during the earth's diurnal revolution, electric resistance increases or diminishes in the same ratio, and increase or decrease of current intensity is a corresponding result; and electric maxima and minima, and also reversal of current, must follow from this cause, as well as from difference or equality of temperature. But as increase or decrease of distance is coincident with increase or decrease of difference of temperature, the two causes intensify each other's effects.

CHAPTER XIII.

THE ELECTRICITY OF THE EARTH AND ATMOSPHERE.

THE AURORA.

THE relations of the aurora to terrestrial and atmospheric electricity present a problem of the deepest interest and importance, whose satisfactory solution must render clear many questions now involved in doubt and obscurity. Hence, during the last fifty years, it has been carefully observed, and a number of important facts in regard to it ascertained. The laws which govern it are still far from being understood, and much conflict of opinion exists in regard to many points; but its electric origin may be regarded as fully established.

This phenomenon occurs in zones surrounding the northern and southern magnetic poles. And observations have been chiefly confined to its occurrence in the north. The northern aurora is known as the *aurora borealis*, the southern as the *aurora australis*, while the term *aurora polaris*, or simply the aurora, is applied to either.

In the United States it is usually first seen at from 8 to 10 P. M., though often beginning much later: and it continues from three to four hours. Its occurrence during the day, also, is probable; though it can only be inferred from coincident effects; the brilliancy of the daylight rendering it invisible.

Some of the great auroras have been seen for several nights in succession ; their occurrence during the intervening days also being highly probable.

AURORAL ARCHES, CORONÆ, AND STREAMERS.—It first appears, usually, as a low arch of light, in the direction of the pole, resembling the dawn of day ; whence its name, aurora, the morning. This arch is often accompanied by a low bank of clouds, lying under it, next the horizon. As the arch slowly rises streamers of light, differing in color, size, and brilliancy, dart up through it ; extending from the horizon to a considerable height above the arch ; their color varying from a pale white to a light red ; though yellow, green, and blue tints have also been observed ; the prevailing tints differing more or less in different localities.

These streamers appear to radiate from a central region below the horizon, cutting the arch vertically, at right angles, as shown in Fig. 58. The streamers sometimes appear to rise from widely separated points in the horizon ; and, as the aurora increases in size and brilliancy, they culminate at the zenith, as shown in Fig. 59, forming a corona of more or less prominence ; one of the most prominent being shown in Fig. 60.

By comparing the three cuts, it will be seen, that if the center of the corona shown in Fig. 59, or Fig. 60, were below the horizon, the appearance would be the same as in Fig. 58. So that, supposing the observer placed below the horizon, under the center from which the streamers seem to emanate, he would see the corona above him, as in Figs. 59 and 60. And, conversely, an observer in the latitude of Paris, looking at the corona, observed in latitude 70° N., Fig. 60, would

Fig. 58—Aurora Observed at Paris, October 3, 1882.

see only the upper part of its southern half, corresponding to the aurora shown in Fig. 58.

In the aurora shown in Fig. 61, seen from the Vega, in latitude 65° N., we have an arch formation without streamers. A series of concentric arch segments, more or less perfect, is seen; the outer one less than a semicircle, and the most perfect of the inner ones greater than a semicircle; the central one, a double arch, with the nucleus of a second double arch above the junction. From an inspection of the figure, it is evident, that the perfect arches would appear as complete circular belts to an observer under the central point near the horizon.

Difference of longitude, as well as latitude, must also modify the appearance: as that portion of the arch which appears to one observer as its summit, appears to another, at a distant east or west point in the same latitude, as its east or west base. And, supposing the first observer placed in the magnetic meridian which coincides with the center of the aurora, the effect of perspective would cause it to assume a different appearance to him, from that seen by the other observer, viewing it from a different angle. A streamer, seen from one position, would appear foreshortened; while at a different angle it would appear elongated: to one observer it might appear as a narrow ray, to another as a broad band.

Hence, we may infer, that we see in the arch, rising from the horizon, the outer edge of a circular belt of electric light, with its varied phenomena of arches, streamers, rays, and coronæ, covering a large area, parallel to the earth's surface, and extending, as it increases in size, from a region surrounding the pole,

Fig. 59—Aurora Observed at Paris, Feb. 4, 1872.

towards the equator: and that its different aspects, at different times and places, and its different phases, as seen at the same time by observers at different points, are greatly modified by its position with reference to the position of the observer.

Fig. 60—Auroral Corona Observed at Bossekop, Lat. 70° N.

AURORAL MOVEMENT, CURTAIN FORMATION.—A peculiar feature of the aurora is the continual movement visible in every part. A streamer darts up rapidly from the horizon, increasing in size and brilliancy; and as rapidly fades away. Along one part of the arch a series of streamers form in rapid succession, giving the impression of an undulatory, horizontal movement, at right angles to the vertical movement of the rising streamers: and, as the intensity of this phase decreases, a similar movement, at some distant point, rises and declines in a similar manner. At times there occurs a curtain formation, composed of parallel rays; appearing either as a single curtain, as shown in Fig. 62, or as a series of curtains, hung one behind the other, showing only their lower margins, as in Fig. 63;

Fig. 61—Aurora Observed from the Vega, at Behring's Straits, Lat. 65° N., March 21, 1879.

undulatory movements occurring, transverse to the apparent vertical position of the rays, like the movements of a banner floating in the breeze.

This appearance is doubtless greatly modified by perspective: the rays which are apparently vertical,

Fig. 62—Auroral Curtain Formation, Observed at Bossekop, Lat. 70° N.

being horizontal; and probably emanating from the edge of an arch; producing the single curtain shown in Fig. 62; or from the edges of several concentric arches, like those shown in Fig. 61; producing the series of

Fig. 63—Auroral Curtain Formation, Observed at Bossekop, Lat. 70° N.

curtains shown in Fig. 63. It is also evident from this, that in the formation of coronæ, the appearance is probably often due to the edge of the arch, with the streamers emanating from it, reaching the zenith of the observer.

AURORAL BANDS.—Sometimes a single streamer spans the heavens from west to east like a band. The author saw such a one at Chicago, Oct. 5, 1882. Appearing at about 10.30 P. M., near the horizon, a little north of west, it extended, within ten minutes, to the eastern horizon, passing near the zenith: and remained visible for more than half an hour. Its apparent width was about four degrees, and its color a light red.

The signal service record, for the same date, describes an aurora, “seen generally throughout New England, as far south as Washington, and, in the northwest, from 10 30 P. M. till after midnight; reaching an altitude of 90° , and covering 90° of the horizon.” Its different colors, in different localities, were “white, blue, yellow, and crimson. Beams, arches, waves, streamers, and patches of light were visible; and, at Washington, frequent flashes of lightning, at the edge of the dark segment.”

HEIGHT OF THE AURORA.—Great diversity of opinion has existed in regard to the height of the aurora above the earth. A great altitude has been assigned to it by some, who argue that the same aurora could not otherwise be visible to observers thousands of miles apart: while others assign to it a low altitude; maintaining that these different observers do not see the same aurora, but different ones, occurring at the same time: since the appearance seen by one, often differs greatly from that seen by another. But, since different *parts* of the same aurora may be visible to different observers, it is evident, that one of low altitude, and great extent, might be seen at points as widely remote from each other as the eastern and western continents; the

electrified stratum of the atmosphere surrounding the polar area, like a circular belt.

The weight of evidence is now in favor of the low altitude; sixty-nine miles above the surface being considered a fair estimate. But strict accuracy is not attainable; since it is impossible for any two observers, at opposite ends of a base line of sufficient length, to fix with certainty on the same point, so as to make an angular measurement. But we can estimate the probable height at which atmospheric resistance would be sufficiently reduced to produce the auroral phenomena; and we have already seen that this plane of least resistance must lie between the dense strata below and the region of high vacuum above; both of which oppose electric movement. Hence the height, given above, may be approximately correct; and yet subject, doubtless, to variation, resulting from difference of atmospheric pressure; low pressure diminishing resistance, and depressing the auroral plane, and high pressure producing the opposite effect.

GEOGRAPHICAL POSITION OF THE AURORA.—Observation shows that the aurora is confined to comparatively narrow belts. It is never seen at the equator, and is rarely visible in the northern hemisphere south of latitude 40° : while in higher northern latitudes, it is seen to the south of the observer; and decreases in frequency and brilliancy, assuming apparently a more southerly position, as the observer moves farther north.

In Fig. 64, we have a chart, giving the results of observations made in the northern hemisphere, by different European observers; which shows that this auroral belt is about 30° in width. Its southern limit,

Fig. 64—Chart showing Isochasmen or Lines of Equal Auroral Frequency.

(From Petermann's Mittheilungen, 20 Band, 1874—IX.)

in the western hemisphere, is shown at Lat. 22° N., Long. 75° W. from Greenwich; and its northern limit, on the same meridian, at Lat. 58° N. In the eastern hemisphere, its southern and northern limits, on the same meridian, are between 47° N. and 77° N.

The increased width and number of the lines, towards the northern limit, show a great increase in the frequency, brilliancy, and duration of the auroras in that region.

It is also found, that the position of this auroral belt varies at different seasons of the year; reaching its southern limit near the equinoxes, and its northern limit near the solstices.

The results given in the above chart must be regarded as approximate, rather than strictly accurate; as the data on which they are based were more or less imperfect.

CAUSES OF THE AURORA.—Having now examined the various phases of auroral phenomena, and their location, we are prepared to investigate more fully the causes by which they are produced.

The earth has already been described as a thermo-electric battery, and the atmosphere as a Leyden jar; the one a generator and the other an accumulator; and, in the combination of the two, we may look for the principal cause of the aurora.

We have seen that electric movement is from higher to lower temperature, producing earth currents on east and west lines, governed by the earth's rotation, and by solar and lunar influence. But the greater difference of temperature between the equatorial and polar regions must produce north and south currents of far greater energy than these east and west currents.

It has also been shown, that a change of potential, in

any portion of the earth's surface, must produce a corresponding change in the stratum of least resistance, in the atmosphere above it; and that a transfer of electricity must occur between this electrified atmospheric area, and the surrounding atmosphere, lying in the same horizontal plane, either from it or to it, as the earth's surface below is positive or negative.

We have, in the aurora, the exact fulfillment of all these conditions. A high earth potential, in the polar regions, must result from the currents flowing in from the warm region; and produce, by induction, a corresponding negative potential in the atmosphere. And, in the belts where these ice-bound polar regions join the warmer region, the principal electric action must take place; producing the auroral arches of white light: while the electricity radiating in opposite directions, north and south from the arch, produces the streamers, beams, rays, bands, and coronæ; as the electric action at different points has greater or less intensity, or meets with varying resistance.

Confirmatory evidence of this view is found in the fact, shown by the chart on page 200, that within the torrid and north frigid zones, where a comparatively even temperature exists, the aurora is not seen; and also in the shifting position of the auroral belt with change of temperature, as already mentioned.

The east and west earth currents must also exercise their inductive influence, giving rise, probably, to the transverse undulations observed in the streamers and curtain formations. And the resultants of these currents, and the north and south currents, are seen in the bands and streamers which often assume a diagonal direction, northwest and southeast, or otherwise.

The stratum, in which these phenomena occur, must have a certain degree of thickness; its upper surface merging into the region of high vacuum, and its lower surface into that of greater density; resistance increasing upwards and downwards from a central plane. Hence, different phases of electric action must occur at different altitudes; corresponding to the different aspects of electric transmission in high and low vacua, seen in laboratory experiments, as described in Chapter X: which may account for the common auroral appearance, shown in Fig. 58, where the arch seems to form a background for the streamers. And, as there is often a series of concentric arches, as shown in Fig. 61, it is easy to see how streamers might radiate from one arch, across the plane of another arch, at a different altitude. And, if one was below, and the other above the horizon, the appearance would be the same as in Fig. 58.

Now, since the causes here assigned are in constant operation, we may infer that there should be a constant aurora; though it does not follow, that it should be everywhere constantly visible. And from the great number of auroras observed in the course of the year, in different parts of the auroral belts, especially in the northern part of the northern belt, it is reasonable to infer, that, with a more perfect system of observation, auroras, of greater or less magnitude, would be seen, at one or more points, every night in the year.

It is also probable that this electric action may be constant, without being always sufficiently intense to attract attention: and that the aurora is the result of its increased intensity.

Other atmospheric phenomena, not usually recognized as belonging to the aurora, may also be due to this

electric action. The peculiar band and arch formation of cirro-stratus clouds often strongly resembling auroral bands and arches, has, by many observers, been attributed to similar electric action; though doubtless occurring at a much lower altitude than that of the aurora.

The existence of strong earth currents during the prevalence of auroras, and of those violent perturbations, known as "electric storms," are well established facts, proved by observations on telegraph lines. During the aurora of Feb. 4, 1872, visible over an area embracing 30° of latitude, and 150° of longitude, these currents and perturbations were observed on all the lines within this area, both land and submarine; being strongest on those having a southeast and northwest direction.

The following description of the auroral storm of Nov. 17, 1882, is condensed from the Signal Service Reports: "Beginning a little before daylight, it was known at first by its interference with telegraphy. For three hours not a wire of the Western Union Telegraph Company could be worked. Late in the afternoon, the trouble seemed to decrease; and, at night, there was a brilliant aurora prevailing over the eastern half of North America, the Atlantic, and northwestern Europe; and all telegraphic service was interrupted. Cables to Europe, and wires to Chicago, could not be worked; annunciators in telephone offices dropped; the switch-board in Albany, N. Y., was ignited; the switch-board and wires at Chicago were burned; and an incandescent lamp was illuminated at St. Paul, Minn. A message was sent from Bangor, Me., to North Sydney, C. B., 710 miles, by the earth current alone, without the batteries; the current being as strong as that

from 100 cells. And the short line from Boston to Dedham, ten miles, showed the disturbing influence as much as the longer lines."

In these observations, as in those cited in Chapter XII, it has been found that whenever the earth connection is severed, at either end of the line, the current immediately ceases; proving it to be an earth current, and not a current in the atmosphere.

The increased intensity of current, on lines having a southeast and northwest direction, noticed during the aurora of Feb. 4, 1872, is confirmatory evidence of the existence of resultant currents, as explained on page 202.

The hours at which maximum and minimum effects were observed, during the aurora of Nov. 17, 1882, correspond exactly to the hours of maxima and minima potential, and current intensity, already cited. A maximum having occurred during the three morning hours, beginning just before daylight; a minimum late in the afternoon, and a maximum again after sunset.

Another cause of the aurora is found in the movement of warm air from the torrid to the frigid zones, and of cold air, at a lower altitude, from the frigid zones to the torrid. The meeting and intermingling of these opposite currents, at different temperatures, must give rise to strong electric action in the atmosphere, similar to that already described as taking place in the earth, and coincident with it. And this action must occur in the stratum next the earth, far below that assigned to the aurora; its intensity increasing with the density of the atmosphere, and hence being greatest at the earth's surface.

This becomes evident, when we consider, that the

greater part of the mass of the atmosphere lies near the earth's surface; being included, probably, within the first nine miles; while the auroral stratum is supposed to have an altitude of sixty-nine miles. Hence this atmospheric electric action would be supplementary to that of the earth, already described; and would have an east and west as well as a north and south direction, as described on page 182.

The influence of the sun and moon, already referred to, must intensify the effects produced by other causes: so that we should expect to find maximum and minimum auroral effects, corresponding to an increase or decrease of intensity, in solar or lunar influence. Observation has shown, that such an auroral maximum occurs, during the recurrence, once in eleven years, of the period of the maximum solar disturbance; that auroras are then more frequent and brilliant than at other times: and we may reasonably infer, that future observation will show the existence of electric maxima and minima, analogous to the tides, and auroral effects corresponding to them.

CHAPTER XIV.

THE ELECTRICITY OF THE EARTH AND ATMOSPHERE.

LIGHTNING AND THUNDER.

FORMATION OF THUNDER CLOUDS.—Our investigation of this subject thus far has been confined chiefly to the electricity of the earth and its inductive effect on the atmosphere; we are now to investigate the electricity of the atmosphere and its inductive effect on the earth.

We have seen, in the Töpler machine, how electricity is generated by the mutual friction and induction of insulated conductors, put in motion by mechanical force; and collected in accumulators which acquire different potentials, and between which a discharge finally takes place, attended with a flash and report. Something analogous to this occurs in the atmosphere. The clouds are large conductors, insulated in the air, moved by the winds, acting inductively on each other and on the earth, and, in other respects, fulfilling the same conditions found in the machine.

As the vapor forming these clouds rises from the earth, it must have, when generated, the same electric potential as that part of the earth from which it rises, and hence the same difference of potential which has been shown to exist in different parts of the earth's surface.

The air laden with this rising vapor, moving along in

currents, and brought into contact with elevated parts of the surface, and with trees, buildings, and other elevated objects, must generate electricity by friction, much in the same way as the carriers on the revolving plate of the machine. And, as the vapor forms into clouds, they become the accumulators of this electricity, in the same way that it is accumulated by the plates and Leyden jars of the machine. And this concentration of electricity in the clouds raises their electric potential; and makes them the nuclei to which the rising vapor is attracted in consequence of its lower potential.

Each infinitesimal drop of vapor is a sphere with its electric charge on the surface; and as these drops coalesce, and form larger ones in the cloud, the charge on each new drop accumulates on the surface; and as the increase of volume is greatly in excess of the increase of surface, the electric surface density must increase in nearly the same ratio; the volume representing electric quantity, which is thus condensed on a reduced surface, producing a corresponding increase of intensity.

Thus as a large body of invisible vapor forms first into light fleecy clouds; and these collect into denser masses; there is a constant reduction of volume, and increase of electric intensity; till the fully formed thunder cloud is the result.

DISCHARGE BETWEEN CLOUDS.—Two or more such clouds, formed in different localities, often many miles apart, and electrified in this manner, must, almost inevitably, be at different electric potentials. And when carried towards each other by opposite atmospheric currents, at different altitudes, and brought within the sphere of mutual electric influence, strong inductive effects are produced; their approach is accelerated by attraction,

and, when brought within proper distance, a discharge takes place from the cloud of higher to that of lower potential: just as a similar discharge takes place between the sliding electrodes of the machine: and the result is chain lightning, of which the spark of the machine is an exact type.

The distance, through which this discharge takes place, depends on the quantity and intensity of the charge, and the difference of potential between the clouds. It may be any distance, from a few yards to several miles. Observation on discharges between clouds overhanging fixed localities, as two mountain peaks, shows that they are sometimes from three to five miles or more in length.

We have seen how sparks, eight to ten inches in length, are produced by the machine; and have tested their energy. If we compare such a discharge to that produced between two clouds, whose magnitude and potential, as compared with those of the machine, are almost infinite, we can form some adequate conception of the enormous energy of the lightning.

When the line of discharge is concealed by intervening clouds, and we see only the illumination resulting from it, the phenomenon is known as sheet lightning. We have the same result, when the spark from the machine, occurring in a dark room, is concealed. Hence, we may reasonably infer, that the discharge between the clouds, like that between the electrodes of the machine, would always present the appearance of chain lightning, if the line of discharge were always visible.

The contorted and bifurcated discharges, known as *zigzag lightning*, and *forked lightning*, like similar discharges in the machine, are doubtless due to differences

of resistance in the air, to the induction of surrounding clouds, and to the mutual repulsion of the molecules of air and vapor within the line of discharge; which, being electrified to the same potential, tend to separate and form resultant lines, under the influence of forces acting at right angles to each other.

Observation shows, that there is usually a succession of discharges between the two clouds, similar to the repeated discharges from a Holtz machine: in which, after the initial charge, electricity is generated by induction alone. This action begins when the edges of the two clouds, at different altitudes, approach within discharging distance, and come into vertical line; and the effect of induction is to accumulate the electricity of the cloud of higher potential at the end nearest to the other cloud, while the electricity of the latter is repelled to the remote end; just as a similar effect is produced by the mutual approach of two differently charged conducting plates or cylinders; the difference of potential between the adjacent parts being thus greatly increased.

The discharge produces a momentary equilibrium, which is again disturbed by induction, as larger areas of the two clouds approach more closely: the residual becoming the initial for a new charge, further condensation taking place, and fresh supplies of electricity flowing in from the surrounding atmosphere. In this way the series of discharges continues, till the clouds unite, and complete equilibrium takes place.

When several such clouds, at different potentials and different altitudes, collect in each other's vicinity; as is usually the case in a thunder storm of much magnitude; the mutual inductive effect is greatly intensified.

Suppose three clouds, arranged in a series, end to end, and so graduated as to potential, that the central cloud is at a mean between the other two. Let a discharge take place from the cloud of highest potential to the central one; a second discharge must quickly follow, from the central cloud to the one of lowest potential: since the first discharge has greatly increased their difference of potential. This second discharge would renew the difference of potential between the first and central clouds, and prepare the way for another series of similar discharges.

The most careless observer cannot fail to have noticed such series of discharges, following each other in rapid succession, in different parts of the sky, during a violent thunder storm.

Observation also shows, that during a thunder shower, there is always an increase of rain-fall, and an enlargement of the drops, within a few seconds after each electric discharge; the time being just sufficient for the rain to descend, if it left the cloud at the moment of the discharge. From which we may infer, that condensation is a result of the discharge; that, in the momentary equilibrium which follows it, the small drops, which were before kept apart by mutual repulsion, from being highly charged and at the same potential, now coalesce, and form the large drops; which, being too heavy to be sustained in the atmosphere, fall.

THUNDER.—As the spark from the machine is the type of lightning, so the snap represents thunder; which is undoubtedly due to the same cause—the sudden and intense vibratory motion of the air, in the line of discharge, producing violent undulations in the surrounding air. A cause which will appear sufficiently

adequate, when we consider the results which must follow from the rush of the enormous energy of a thunder cloud, along a line, perhaps five miles in length, in an infinitesimal fraction of a second.

And here, as in the case of the spark, it is quite unnecessary to suppose the passage of any material substance through the air, producing partial vacuum and collapse, or the occurrence of anything in the nature of an explosion, producing similar results. It is more in accordance with the known laws of electric movement, to suppose that the electric energy has used the air as the medium in which to travel; and thus produced the vibratory motion.

Common observation shows, that in explosions where the expenditure of energy must often be far less than in the electric discharge between clouds, the vacuum and collapse shatter window-glass in the vicinity; while the heaviest thunder produces only a slight tremor in adjacent buildings; proving that such vacuum and collapse cannot result from an electric discharge.

The succession of reports accompanied by a continuous rumble, heard so frequently during a thunder storm, has been considered, by some observers, as a series of echoes from a single report; and by others, as a number of separate reports, from discharges occurring simultaneously, at different distances from the observer, and heard in the order of their distance.

An echo requires the intervention of an extended surface, as a wall or its equivalent; and observation shows, that the under surface of a dense thunder cloud is of this character, being remarkably uniform, though its upper surface may be quite the reverse: and it is also evident, that this under surface, resting on the denser

strata of air, and sustaining the weight of the mass of air and vapor above, must have greater density than the upper surface. Hence we may reasonably infer, that this surface, and that of the earth below it, fulfill the conditions necessary for a series of echoes.

The hypothesis of simultaneous discharges, at different distances, may also be true in certain instances: as it is quite possible that such simultaneous discharges frequently occur. But the succession of reports, often following each other with marked regularity, and steadily decreasing in volume and intensity, is not fully explained by this hypothesis, while it is entirely in accordance with the character of a series of echoes.

The re-adjustment of electric energy between different parts of a large cloud, which must follow the primary discharge, gives rise to numerous minor discharges; whose sound, mingling with that from the larger air waves, causes the rumble; analogous to the crackling sound from similar minor discharges in the machine. A premonitory rumble, from a similar cause, often precedes the heavier discharge; just as the crackling precedes the discharge of the machine.

If the cloud were a perfectly homogeneous conductor, like a metal cylinder, this could not occur. But as it is a mass of vapor, composed of drops insulated from each other by air spaces, each particular drop having its own electric charge; and different parts of the cloud having different densities, and hence differing in conductivity and resistance; and condensation, with increase of potential, following the discharge, as already shown, such minor discharges, with the accompanying roar and rumble, are inevitable. Also the development of the residual, after the primary discharge, which, in a large

cloud, must in itself have great energy, greatly intensifies these effects.

DISCHARGE FROM THE CLOUDS TO THE EARTH.—We have already seen that the potential of the atmosphere, and hence of the clouds, is almost invariably positive with reference to that of the earth. Hence the earth's surface under a thunder cloud, and all objects connected with it, become negatively electrified by induction, to the same degree that the cloud is positive; electricity, equal to the charge of the cloud, being repelled from the earth's surface to its interior. A result of this difference of potential is a strong attraction between the earth and cloud, by which the cloud is drawn towards the earth; and, unless its potential is reduced by discharge into another cloud, a discharge to the earth is inevitable, whenever, from reduction of distance, the resistance of the air becomes less than the electric tension of the cloud.

When there are two clouds at different altitudes, and a discharge takes place from the upper to the lower cloud, the difference of potential between the latter and the earth, being thus increased, the liability of a discharge from it to the earth is increased in the same ratio.

If there are elevated objects, such as trees and buildings, on the surface below, the resistance between them and the cloud is less than that of the surrounding flat surface; not only on account of reduced distance, but also on account of the points and angles which they present. Hence, we find, that trees, flag-staffs, telegraph poles, church spires, chimneys, and projecting corners of roofs are much more frequently struck by lightning than flat surfaces.

Good conductors, such as tin gutters, metal cornices, and ornamental iron work, also offer far less resistance

than imperfect conductors, like wood, brick, and stone; both from their superior conductivity, and their projecting edges and points; and when connected with a building and not connected by a metallic conductor with the earth, greatly increase the liability of the building, both to receive the electric discharge, and to sustain injury from it, by making the building its terminus instead of the earth.

DISCHARGE FROM THE EARTH TO THE CLOUDS.—As already shown, the electricity of a large cloud, like that of a cylinder, may be so distributed by the proximity of one end to another cloud, at a lower potential, or to an elevated portion of the earth's surface, that the potential of this end shall be higher than that of the remote end. The potential of the earth's surface, beneath it, must also be similarly affected by induction, in reverse order; being negative where the cloud is positive, and positive where the cloud is negative. If, under these circumstances, the difference of potential between the negative end of the cloud and the earth becomes greater than the resistance of the air, a discharge from the earth to the cloud must occur; the discharge in this, as in all other cases, being from higher to lower potential.

These conditions are similar to those of the three clouds already referred to: so that a discharge from the positive end to another cloud, or to the earth, may increase the difference of potential between earth and cloud at the negative end.

The resistance of the earth, also, over such an extensive area, retards the restoration of surface equilibrium after the discharge from the positive end; and increases the liability of the return discharge from the earth to the cloud, in the ratio of this resistance to that of the vapor of the cloud.

In this case, as in that of a discharge from the clouds to the earth, elevated objects reduce the resistance, especially if they are good conductors, or furnished with sharp angles or points; and become the electrodes through which the discharge takes place.

LIGHTNING RODS.—Franklin first proposed the lightning rod. The identity of lightning and electricity, strange to say, was unknown, till, by the erection of a metal rod at his suggestion, and subsequently by his well known kite experiment, sparks were drawn from the cloud, Leyden jars charged, and various similar laboratory experiments, previously known to electric science, performed by means of atmospheric electricity.

The first lightning rod was erected, May 10, 1752, a month previous to the kite experiment, by M. Dalibard, in France, according to the plan proposed by Franklin for testing the identity of lightning and electricity: and sparks similar to those from the electric machine were drawn from it.

The identity of lightning and electricity having been established, Franklin showed how the rod could be used as a means of protecting buildings. The result is the lightning rod, as we now have it, in its numerous forms. And though ignorance, greed, and dishonesty have cast their shadow upon it, yet thousands of well constructed rods, standing as the silent guardians of life and property, sufficiently attest its value.

The proper construction of lightning rods was recently investigated by a conference of leading English scientists, specially appointed for that purpose: among whom were several eminent electricians. And, after three years of thorough investigation, during which practical information was collected from all parts of

the world, a code of rules for the construction and erection of lightning rods, or conductors, was adopted December 14, 1881; which is substantially as follows:—

RULES FOR THE CONSTRUCTION AND ERECTION OF LIGHTNING CONDUCTORS.

POINTS AND UPPER TERMINALS.—As the point of the upper terminal, from its peculiarly exposed position, is liable to be fused by a heavy charge, it should not be sharper than a cone whose height is equal to the radius of its base. But, to secure the peculiar advantages derived from sharp points, three or four such points made of copper, each about six inches long, should be attached to a copper ring; which should be screwed or soldered to the terminal, about twelve inches below its highest point. And all points should be so platinized, gilded, or nickel-plated, as to resist oxidation.

The number of terminals required, their height above the building, and the number of conductors connected with them, depends on the size and style of the building, and the conductivity of the material of which it is constructed.

All elevated parts, such as turrets and spires, should be protected by terminals: and especially chimneys, whose liability to receive a discharge is greatly increased by the heated air and soot.

Factory chimneys should have a copper band round the top; with stout, sharp, copper points, each about twelve inches long, projecting from it at intervals of two or three feet; and specially guarded against oxidation. And the conductor, attached to this band, should be attached to all bands and metallic masses in or near the chimney.

SPACE PROTECTED.—No definite rule can be given

as to the space protected by a conductor; as opinion and practice vary in regard to it: but there is no well authenticated instance of a building furnished with a properly constructed conductor, having been injured by lightning within a conical space, having the point of the upper terminal for its apex, and the radius of whose base equaled the height of the conductor.

ATTACHMENT TO BUILDING.—The evidence against the use of glass or other material, in order to insulate the conductor, is overwhelming; and insulation may be regarded as unnecessary and mischievous. The attachment to the building should be made with metal fastenings; which should be of the same metal as the conductor itself, to prevent corrosion from galvanic action. They should be of adequate strength: and each should support its proper proportion of the weight. They should not compress or distort the conductor; and should allow free play for its expansion and contraction.

As far as practicable, it is desirable that conductors be connected with extensive masses of metal belonging to the building, both internal and external; except soft metal pipes, which, from low conductivity for heat and electricity, are liable to fusion. Gas-pipes, especially, should not be so connected on account of liability to ignition of the gas by an electric spark, resulting from fusion of the pipe, or from bad joints: but the inlet and outlet pipes of large gas meters should always be electrically connected with each other, as a protection against such accidents from the electric resistance of joints; which is sometimes greatly increased by india-rubber packing.

Church bells, inside well protected steeples, need not be connected with the conductor.

ORNAMENTAL IRON WORK.—All vanes, finials, ridge iron work, and similar ornamental metal work, should be connected with the conductor: and it is not absolutely necessary to use any other point than that afforded by such ornamental work; provided the connection be perfect, and the mass of iron considerable. As, however, there is risk of derangement through repairs, it is safer to have an independent upper terminal.

MATERIAL FOR CONDUCTOR.—The best material for a conductor is copper; its weight not less than six ounces per foot run; and its conductivity not less than ninety per cent. of that of pure copper. It may be used either in the form of tape, or of wire cable, in which no wire should be less than No. 12 B. W. G. Iron may be used, but its weight should not be less than $2\frac{1}{4}$ pounds per foot run. And all iron conductors, whether galvanized or not, should be painted, as a protection against oxidation. Copper conductors may be painted or not according to architectural requirements.

FORM OF CONDUCTOR.—The form of the conductor does not seriously affect its conductivity: and great extent of surface in proportion to mass is not essential: but sectional area of mass is highly essential, and should always be sufficient to carry the heaviest charge without danger of fusion of the conductor, or division of the current.

The rod is desirable for long upper terminals, on account of its rigidity; but the necessity of frequent joints, and the difficulty of avoiding disfigurement of the building, are serious objections to its use for the body of the conductor.

Tubes are liable to the same objections; their larger diameter, and the collars necessary for their joints, rendering them more conspicuous and undesirable.

Twisted wire cables have the advantage of comparative freedom from joints; but their interstices afford a lodgment for smoke, dirt, and water; especially if small wires are used: which are also less capable of resisting oxidation than large wires.

Tape has the special advantages of requiring but few joints; of their being easily made, where necessary; and of being flat and flexible, so that it can be adapted to the outlines of a building, or countersunk in it and painted over, so as not to be conspicuous.

Conductors should not be bent abruptly round sharp corners: and in no case should the length of conductor between the two points of a bend be more than one-half greater than the straight line joining them. When practicable, the conductor may pass straight through a projection; the hole being made large enough to allow it to pass freely, without compression.

The reasons for these precautions are found in the liability to discharge from a sharp angle, or across a short space in a bend.

JOINTS.—The most fruitful source of danger in conductors is from bad joints. Screwed, scarfed, or riveted joints, however well made, are certain to rust and corrode in time; introducing nodes of resistance, at which the electric charge is liable either to fuse the conductor, or to leave it and enter the building.

No joint is electrically perfect that is not metallically continuous, and as absolutely free from resistance as any other part of the conductor: and careful soldering, in addition to the screwing, scarfing, or riveting, is the only certain means of securing this, which has borne the test of experience.

EARTH CONNECTION.—A good earth connection, for

the lower terminal, is of the utmost importance; and in a majority of cases of injury to buildings from badly constructed conductors, such injury is traceable to imperfect earth terminals.

The terminal should connect with damp earth, at a sufficient depth below the surface, to insure *permanent* dampness, and hence permanent conductivity. And, to render this connection more complete, it should bifurcate below the surface; and be connected by soldering, with a mass of metal, buried in the earth. The hole, in which this mass is buried, should be filled to the surface with cinders or coke, to facilitate the percolation of water; and any available drainage of pure water, from rain water pipes or otherwise, connected with it.

The metal mass may be of copper or galvanized iron, having about eighteen square feet of surface. And where permanently damp earth is not available, it should consist of three or four hundred pounds of iron.

Where the use of large iron water or gas mains is available, a connection by a copper strip, can be made with them; no risk being incurred by such connection, as in the case of internal supply pipes.

INSPECTION.—Periodical inspection, and careful electric testing, are requisite to maintain the system in efficient order; as points may corrode or become fused, joints become electrically imperfect, connections become severed above or below ground, or other imperfections occur, from alterations in the building, and the carelessness or ignorance of occupants or workmen.

The author has, on his house, a copper tape conductor, constructed in accordance with these principles, and erected twenty-three years ago; and neither the house,

nor the conductor, has ever received the slightest injury from lightning; while numerous instances of damage to buildings and conductors have occurred in the vicinity. Which, considering the length of time, the exposed position, and the repeated thunder storms of great severity, which have occurred, is strong negative evidence of the value of the conductor, and the correctness of the rules here given.

SILENT DISCHARGE.—The protection afforded by a lightning conductor does not consist, so much, in its being the avenue by which a destructive discharge may pass harmlessly between the earth and cloud; as in preventing its occurrence, by a gradual, silent discharge through the points of the conductor; by which the accumulated energy is reduced, before it can acquire sufficient tension to overcome the resistance of the air, and produce a full, sudden, disruptive discharge.

This is strikingly illustrated by the gradual, silent discharge of a large, powerfully charged Leyden battery, through the point of a cambric needle; and is confirmed by the brush discharge, often observed, during thunder storms, on the points of lightning conductors, and on the tips of the masts and yard-arms of ships.

As a building must be regarded, electrically, as an elevated part of the earth's surface, the importance of as perfect an electric connection between it and the conductor, as practicable, is apparent, in order to secure the full benefit of protection in the manner described; which is impaired by the resistance caused by the use of insulators.

It is also apparent, that the conductor affords equal protection whether the discharge is from the cloud to

the earth, or from the earth to the cloud; as in either case, the discharge will follow the path of least resistance; which is always through the conductor, when properly constructed.

HEAT LIGHTNING.—The phenomenon, known as *heat lightning*, is probably nothing more than the ordinary electric discharge from clouds invisible to the observer, and so distant that the thunder is inaudible. Such lightning is generally observed at night, near the horizon; and close observation will show, either the existence of clouds, indistinctly visible in the darkness, or the probability of the discharge occurring from clouds below the horizon.

Its existence, independent of clouds, is claimed from the fact, that it has been observed when no thunder storm had occurred within a radius of one hundred miles. But, not only lightning, but clouds are often visible at greater distances. On the level surface round Chicago, the author has frequently observed heavy thunder storms, eighty miles distant, as shown by subsequent reports, when both clouds and lightning were distinctly visible, though the thunder was not audible.

TORNADOES.—As an electric origin has been claimed for tornadoes, it is proper to remark, in conclusion, that recent investigation has demonstrated that they are chiefly due to currents of air, generated by differences of atmospheric temperature and pressure, and modified by other causes: and while electricity may intensify their force, it cannot be considered as their primary cause.

NOTE REFERRED TO ON PAGE 118.

The brush from K makes its appearance first, and increases in length till the brush from V appears; after which it decreases in the same ratio as the brush from V increases, till the discharge occurs, when both disappear. This is sufficiently explained by increase and decrease of difference of potential at different points. As the potential of the revolving plate A increases, the difference of potential between the inside coating of the jar C , and that part of A which receives the charge from it through the comb K , decreases, as indicated by the decrease in brush-length, till the potential of both is the same, when the brush disappears.

In like manner the potential of that part of the plate A , passing the comb L , continues to increase till it equals the potential of the inside coating of the jar D ; and this charged surface, passing on to the comb H , the surplus of charge which D , from increase of potential rejects, escapes through H to the comb V , and from V to that part of the plate A between V and K , as indicated by the increase of brush-length from V .

This process is greatly intensified by the inductive effect of the high potential of the lower part of inductor T , and low potential of the upper part of inductor X , by which electricity is repelled from the corresponding lower part of the plate A to its corresponding upper part.

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