ALPHABET OF ELECTRICITY.

BY

W. MULLINGER HIGGINS, F.G.S.

PRICE HALF-A-CROWN.

ALPHABET OF ELECTRICITY,

FOR

THE USE OF BEGINNERS.

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PLAN OF THE WORK.

THE term Electricity has, in the present day, a much wider signification than was given to it at any former period. The science, even in its most restricted sense, was quite unknown to the ancient philosophers, and has only recently received an adequate attention from the students of nature. It is true that Thales, Theophrastus, Pliny, and others of the learned Greeks and Romans, were acquainted with one electrical phenomenon, but they had not the most remote idea of the agent that produced it, much less of its extensive distribution, and its general influence upon bodies. In the writings of these philosophers, it is stated that amber has the property, when rubbed, of attracting small pieces of straw and other light substances. This was almost the only electrical phenomenon known till the year 1600, when Dr. Gilbert, a judicious and learned observer, published a work on magnetism, in which he mentioned several new facts attributable to electrical agency, drew the attention of philosophers to this longneglected object of investigation, and thus became the founder of one branch of the science of electricity. Since this period, our knowledge of the electric agent has been progressively increasing; it has been found to develope itself under circumstances in which it was scarcely expected, and phenomena which were considered to originate from distinct causes, have been proved analogous or identical.

For a long time it was supposed that the agent called Electricity could be excited only by friction, and at that time all the phenomena produced by this agent, thus excited, were classed together under the general term Electricity. But it has been since discovered that it may be influenced and set free by the combination of metallic contact and chemical action, by the contact and disunion of the poles of a magnet, by the circulation of heat through metals, and by the muscular action of certain fishes. The term Electricity, therefore, as applied to a branch of knowledge, is of much wider signification at the present time than at any former period. This extension of the science has made a subdivision necessary, and hence we have the subordinate sciences of Common, Voltaic, Magneto, Thermo, and Animal Electricity.

So rapidly have facts been discovered in our own day, that it has been difficult for those who have not paid an almost undivided attention to the subject, to keep pace with discovery; and every one has felt that from the constant increase of facts, it was nearly useless to attempt a combination of the numerous experiments and observations distributed through the pages of our own and the continental journals. To this circumstance we may attribute the want, in every language, of an entire series of introductory papers on the science of Electricity.

In this attempt to supply the deficiency we shall experience many difficulties. As no author has preceded us in some branches of our subject, we must collect for ourselves the facts which are distributed over the pages of the scientific journals; and when this has been done, we have the still more difficult task of stating and explaining them in language suited to inform an individual who is entirely ignorant of the science. Should the author succeed in attaining these ends his desire will be fulfilled, but his readers must not be unmindful that his object is to give a description of those general and fundamental truths which illustrate principles, and not to detail those subordinate results which are dependent on them. If a student should wish to know the construction of the human frame he must learn the connexion and relative dependence of the bones, before he can understand the ramification and action of the nerves and muscles. So, if the student of inorganic nature would thoroughly investigate a science, he must first acquire its principles, and he will then find little difficulty in estimating the importance and relations of the details. We, therefore, shall best meet the wants of our readers, by giving our principal attention to the fundamental truths of the science of Electricity, hoping that the reader will not want for an incitement to further inquiry, when these have been acquired.

In this volume we shall attempt to detail some of the most important facts relating to common, or ordinary Electricity.

ALPHABET OF ELECTRICITY.

THE WORD ELECTRICITY.

The word Electricity, like many other terms in science, is derived from the Greek. Theophrastus, who lived three hundred years before the Christian era, is said to have observed that a piece of amber, when smartly rubbed upon a woollen cloth, attracted, even at the distance of several inches, chaff, feathers, and other light substances. Amber, which is a yellowish translucent substance, supposed to be of vegetable origin, though it occurs as a mineral, is termed *electron*,[1] in Greek, and the term electricity is derived from it, the termination being altered in the same manner as in the words "mendicity," "simplicity" and others.

The word Electricity is now used as the name of

(1) ʼηλεκτρον, supposed to come from ʼηλεκτωρ "the sun," because amber has a luminous appearance when rubbed.

that science which comprehends all those facts which are known, concerning the agent which causes amber, when rubbed, to attract light substances. And, however unimportant that agent may now appear to the reader, he will hereafter find, that it acts a prominent part in many of the changes that are going on in nature, and is absolutely necessary for the very existence of the present state of the earth.

THE AGENT OR CAUSE OF ELECTRICAL PHENOMENA.

Philosophers have long perplexed themselves in endeavouring to determine the agent which produces electrical phenomena. Some have imagined that it is a subtle fluid existing in all substances, and others that there are two electric fluids, having opposite qualities; while, on the other hand, some persons have attributed all electrical phenomena to some peculiar condition of the particles of the substance that exhibit the phenomena. We shall endeavour to avoid as much as possible, allusion to any particular notion concerning the electrical agent, and to confine our attention to facts; but at the same time it may not be inadvisable to premise that theory has been so interwoven with the explanation of facts, that they cannot now be separated. Thus, for instance, we are accustomed to say that a substance is in a positively or negatively electrified state, which admits that the agent may be increased or diminished in that substance. We also speak of some substances as conductors of the electric agent, and of others as non-conductors. In the enunciation of every fact, we admit the theory, that the electric agent is itself a substance contained in all substances, and capable of taking different states. However anxious therefore we may be to divest our explanations of theory, we must admit that it dictates all our terms, and is blended with all our inquiries.

Effects of Electricity.

Among the effects produced by electricity when accumulated, we may mention the attraction and repulsion of light substances, the deflection of the magnetic needle, the formation of magnets by its passage through steel, the production of chemical action on certain compound bodies, and of light and heat in some instances, as well as the excitation of nervous and muscular power when acting upon the animal system. By all these effects the presence of the electric agent may be determined. The circumstances under which these effects are produced will be subsequently explained.

Of Excitation.

The natural electric state of a body may be disturbed in various ways, but chiefly by friction. If a piece of sealing-wax be rubbed with a woollen cloth, it becomes possessed of a property which it did not evince previous to the act of rubbing, namely, the capability of drawing to itself any light substances which may be presented to it. This property is due to the excitement of a new electrical condition, and when a body acquires this power as the result of friction, it is said to be excited. All substances are susceptible of excitement, although it was long supposed by electricians, that it could only be produced upon a few, which they called electrics. Nor is it necessary that the substances which are rubbed together should be different in kind, for Epinus found that when two equal pieces of glass were rubbed together, they were both excited. The friction of a liquid or a gas against a solid will also produce electric excitement.

But there are other means of exciting a substance. If zinc filings be sifted through a silver sieve, both the zinc and the silver will have their natural electric condition disturbed, and the same will result from sifting silver filings through a zinc sieve. Electricity is also developed during the cooling of fused bodies, and also when a substance is leaving a liquid for a gaseous state. In all these cases Electricity is set free by friction, either upon the surface or between the particles of the substances employed. All the phenomena which result from the Electricity developed in this manner, are classed under that division of the science of Electricity now usually called common or ordinary electricity.

Ordinary Electricity, which is to be the subject of our present investigation, is so called, because it is of most frequent occurrence. Its principles of action were understood, and its phenomena almost fully investigated before the other sources of Electric action were known. This branch of the general science of Electricity will, we think, be best explained by considering, first, those facts which entirely regard the electric agent itself; and, secondly, the influence it has upon substances in general and in particular.

GENERAL FACTS.

The general facts relating to ordinary Electricity may be considered under the following heads :—

1. Attraction and Repulsion.
2. Transference.
3. Distribution.
4. Induction.

ATTRACTION AND REPULSION.

It has been stated, that an electrified substance has the power of attracting any unexcited body that may be near it; but this is only a transient effect; for, after the two substances have been in contact for a short time, they mutually separate, and are said to repel each other. Thus, if a small ball of dry elder pith be suspended by a silken thread, and a dry glass tube, that has been well rubbed with a piece of silk, be brought near, the ball will approach and adhere to the tube. But after it has been in contact a few seconds, it will recede, as though the attractive power had given place to a repulsive. If a stick of sealing-wax, excited by a woollen cloth, be brought near the ball when it is thus repelled by the glass, it will be attracted to it. The same series of phenomena will be observed if the ball be first touched by the sealing-wax, and the glass rod be held towards it after its repulsion.

From these experiments it would appear evident that the effect produced by the glass is directly opposed to that of the sealing-wax; for when the one attracts the other repels, and yet, when the pith-ball is unexcited, it would be attracted by either. This may be accounted for in two ways: first, by the supposition that the electric agent obtained from glass is different in kind from that obtained from resin; or, secondly, that the electricity is the same in both instances, but existing in different states, or, in other words, that glass, when excited, possesses more than its natural quantity of the electric agent, and resinous bodies less. Some philosophers have adopted one opinion, some the other. Those who consider that sealing wax and glass contain different kinds of electricity, denominate that of the former resinous, that of the latter vitreous electricity. Those who have adopted the other opinion, call the electricity of glass positive, and that of sealing wax negative; this phraseology we shall adopt.

It has been stated, that a substance repelled by one electric condition, will be attracted by the other; but it will be necessary to follow up this result somewhat more closely, and inquire into its cause. When a positively or negatively excited substance is brought near to a substance in its unexcited or natural electric condition, it exerts an attractive force. If the attraction be so strong as to cause the non-excited substance to adhere to that which is excited, then it is put into the same state as the excited body. Thus, if the electrified substance be excited with positive electricity, that is, if it be made to possess more than its natural quantity, it will impart a portion to the substance which it attracts, and they will both be in a positive or *plus* condition; but if it be in a negative state, it will take a portion of electricity away from the substance that is brought into contact with it, and they will both be in a negative or *minus* state. Now in both these instances repulsion is the result, from which it is evident that two substances in the same electrical condition, whether that be negative or positive, repel each other.

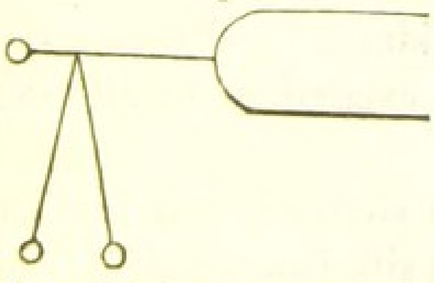
But if we bring a positively electrified substance near one in a negative state, or the reverse, they attract one another.

Electroscopes and Electrometers.

These are the general laws of attraction and repulsion, as resulting from the electric condition of substances. Several instruments, formed upon the principles of attraction and repulsion, have been invented to detect or to measure electricity; some of which may be now described. Those that are merely intended to prove its presence, are called *electroscopes;* those which measure its quantity or intensity, that is, force, are called *electrometers.*

The pith-ball electroscope (fig. 1) is the most simple. It consists of two pith balls attached to the ends of a cotton thread of any length that may be required. When these balls are placed upon an excited body, the conductor of an electrical machine for example, they will be charged with the same

Fig. 1.

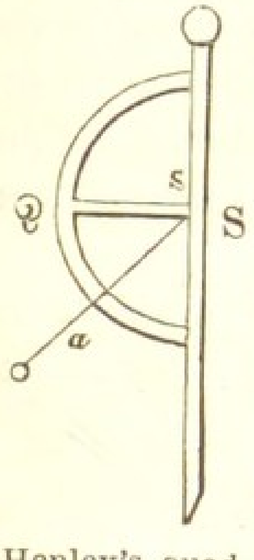


The pith ball electroscope, suspended to the prime conductor of an electrical machine.

electricity, and repel each other, thus proving the presence of electrical excitement.

Henley's Quadrant Electrometer (fig. 2) consists of a wooden or brass upright S, to which is attached a graduated semicircle Q, having a light wooden arm or pointer *a*, so fixed, that when it is horizontal, it may be parallel to the line which would divide the semicircle into two quadrants. To the end of the pointer is attached a pith ball. If this instrument be placed upon an excited substance, the arm will be raised, and by the number of degrees which it indicates, a comparative estimate may be formed of the intensity of the electricity, but without any reference to its quantity.

Fig. 2.



Henley's quadrant electrometer.

Positive and Negative States.

We may now proceed to inquire into the circumstances which regulate the condition of an excited body, and endeavour to determine why one substance is charged positively and another negatively.

The same substance may be excited with either positive or negative electricity. This may be done by employing rubbers of different kinds, by changing the texture of the substance to be excited, or by altering its colour.

A smooth glass tube will be charged with positive electricity when rubbed with a silk handkerchief, and with negative electricity when rubbed with the back of a living cat. This is an instance in which the nature of the rubber governs the electric condition of the excited body.

An alteration in the texture of the substance to be excited will also influence its electric state. Thus, according to an experiment made by Cavallo, if a stick of sealing-wax, having a smooth surface, be rubbed with an iron chain, negative electricity will be developed, but if the surface be roughened, positive electricity will be produced.

The colouring matter contained in a substance will also have an influence in the production of a particular electric state. If white and black silk be rubbed together, the black will become negative, and the white positive.

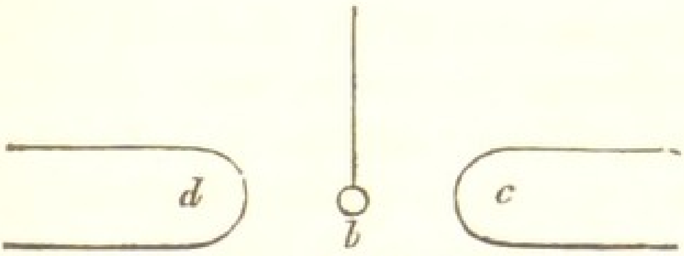
The mention of these experiments leads to the remark, that whenever two substances are rubbed together, they are both excited, and are in an opposite condition. If sealing-wax be rubbed with flannel, it is charged with negative electricity, but the flannel is at the same time rendered positive.

Experiments on Attraction and Repulsion.

These are the most important principles relating to and connected with the phenomena of attraction and repulsion. But it may not be altogether useless to mention, before we pass on, a few experiments illustrating the phenomena we have described. And we would take this opportunity of recommending the student to perform these experiments; for we are certain that he will gain more information by this means, than by reading many volumes.

Experiment 1. Being a pith ball, *b*, (fig.3) suspended by a silk thread near to the excited conductor, *c*, of an an electrical machine[1], and it will first of all be attracted by the electrified body, and afterwards repelled. If an unexcited substance, *d*, a brass cylinder for instance, be then placed on the side opposite the conductor, the ball will be attracted to it, and after parting with its electricity, will be again attracted to the excited body; and in this manner a constant vibratory motion will be kept up till all the electricity of the excited body is carried away.

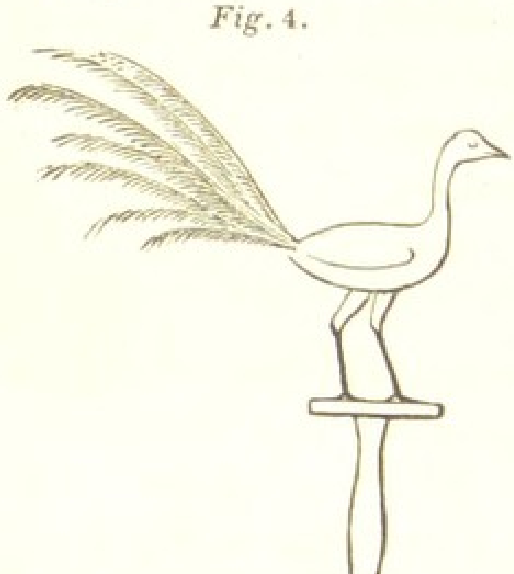
Fig. 3.



Experiment to show the phenomena of attraction and repulsion.

Experiment 2. Take a glass bird (fig.4) having a tail of finely spun glass, and placing it upon the conductor of an electrical machine, charge the conductor. A portion of the electricity thus obtained, will be given off to the atmosphere, and, diffusing itself among the glass threads that compose the tail, will produce a repulsion between them, and cause the tail to expand.

Fig. 4.

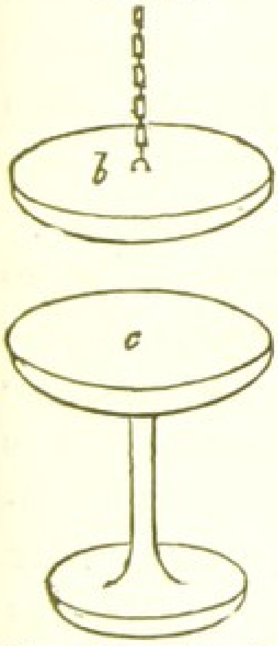


Experiment to show that bodies similarly electrified repel one another.

(1) An electrical machine is an instrument employed to obtain the electric agent in large quantities, and will be hereafter described.

Experiment 3. Suspend a brass plate, *b*, or a disc of pasteboard covered with tin-foil, to the prime conductor of an electrical machine, and place beneath it at a short distance a similar one, *c*, communicating with the ground by a conductor. If paper or pith figures be placed upon the lower plate, they will, as soon as the machine is put into action, jump from one plate to the other, being alternately attracted and repelled by each plate.

Fig. 5.



Experiment to show attraction and repulsion.

TRANSFERENCE OF ELECTRICITY.

There are some substances that possess the power of conducting electricity, and others that do not. If a positively electrified body be touched with any metal held in the hand, its state is immediately changed, and its surplus electricity is carried off to the earth, because the metal and the human body are both conductors of electricity. But if the same excited body be touched with a glass rod, its electricity will not be carried away, because glass is a non-conductor of electricity. Here then we have two classes, conductors and non-conductors, under one of which every substance may, in a general arrangement, be placed. But were we strictly to follow the result of experiment, we should rather say that there is a progressive order in the conducting powers of substances, beginning with those which conduct best, and ending with those that possess least of this power. To form such an arrangement as this, is a task of extreme difficulty; for although we can easily determine which substances conduct best, and which least, it is almost impossible to fill up the series in a natural order.

It is, however, more than probable that all bodies are conductors of electricity, though there are some that possess the power in an almost inappreciable degree. For all practical purposes, therefore, it is sufficiently accurate to divide substances into conductors and non-conductors. Some writers have attempted to form a table of the order of electrical conductability, in which they pretend to determine the precise power (in this particular) of every substance in relation to others. But when we consider the compound character of many of these substances (some of their constituents being conductors, some non-conductors), the influence of temperature over their conductability, and the difficulty of ascertaining it under any circumstances, we are quite convinced that they attempt a classification which cannot be founded upon accurate experiment. In the following tables we have given a list of conducting and non-conducting substances, each table beginning with the most perfect of its class.

Conductors.	*Non-conductors.*
The Metals—silver and copper being the best.	Shell lac.
Dilute Acids.	Amber.
Saline solutions.	Resins.
Metallic ores.	Sulphur.
	Wax.

Conductors.	*Non-conductors.*
Sea water.	Glass.
Spring water.	Silk.
Ice.	Hair.
Snow.	Feathers.
Living vegetables.	Dry paper.
Living animals.	Dry atmospheric air.
Salts soluble in water.	Baked wood.
Rarefied air.	Porcelain.
Vapour of alcohol and of ether.	

It is worthy of notice that the conducting power of most bodies is influenced by their temperature. Water, as will be seen by its place in the foregoing table, is, in its liquid state, a good conductor; but in the form of ice its conducting power is almost entirely destroyed. On the other hand, by raising the temperature of water, its conducting power is increased. Glass is a non-conductor at ordinary temperatures, but becomes a tolerably good conductor when heated to redness; and the same remark applies to charcoal.

Insulation of Electrified Substances.

When an excited substance is placed upon or supported by a non-conductor, it is said to be insulated. Thus, if a pith-ball be suspended by a silk thread, and then charged with electricity by an excited stick of sealing-wax or a glass tube, it is insulated, for both silk and air are non-conductors. And so also, when an electrified body is placed on a stool having glass legs.

The insulating power of air chiefly depends on its density [1] and dryness. When air is in a rarefied state, it conducts electricity, and also when it contains the vapour of water. But under the usual pressure of the

(1) See ALPHABET OF PHYSICS, p. 44.

atmosphere, and in a perfectly dry state, the air is a non-conductor.

From these statements it will be evident that a body may always receive and be kept in a particular electrical condition by insulating it. When we hold it in the hand, or place it upon a table or on the ground, it is impossible to electrify it, because the electricity is carried away by that on which it rests. But if it be suspended by a silk thread, and hung to a glass stand, any electrical condition may be communicated and preserved, if the atmosphere be at the time in a perfectly dry state.

It was long supposed that conductors could not be excited, and the early electricians divided substances into *electrics* and *non-electrics*, as well as conductors and and non-conductors. This is one of those singular instances in which an oversight in the original experimenter introduced an error which has descended from one age to another without detection. A conductor cannot exhibit excitation when held in the hand, for as rapidly as the electricity is developed it is carried off by the body of the person who holds it. But if the conductor be insulated, it may be excited as readily as a non-conductor. Let *c* (fig. 6) be a brass cylinder, and *g* a glass handle. If the cylinder be rubbed with a cat's skin, it will become electric. There is in fact no body which will not develop electricity in some degree, when properly insulated.

Fig. 6.

Method of exciting a conductor.

Dissipation of Electricity.

The principal difficulty in the performance of electrical experiments, is the want of means by which to keep a body in the same electrical condition. When an excited body is placed under circumstances in which the insulation is not perfect, the electricity is lost.[1] Now there are three circumstances that tend to deprive a substance of its electricity.

1. When the solid which supports an excited substance is a conductor, however imperfect it may be, its electricity will be in some measure dissipated. This may, however, be prevented by giving to the substance a proportionate length; for although electricity may be made to pass a short distance through all substances, there is a length beyond which many of them become insulators.

2. The successive contact of portions of air will assist in dissipating the electricity of any substance. Let it be imagined that the air with which an excited ball is surrounded, may be divided into a series of layers.[2] Then, upon the principles of attraction and repulsion, already explained, the nearest layer being in its natural condition, would be drawn to it, and, after receiving or parting with a portion of its electricity, would be repelled. The next layer would then be attracted and repelled in the same manner, and this process would continue until the whole of the electricity of the

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(1) Technically, *dissipated*. (2) Technically, *strata*.

substance had been dissipated. Now, although the air is not thus divided, yet this action is constantly going on, and particle after particle is attracted and repelled, until the natural electric condition of the substance is restored.

3. The deposition of moisture upon the surface of a non-conducting medium, will assist in dissipating the electricity of the excited substance with which it may be in contact. This is the source of more difficulty than any other circumstance, and is the cause of nearly every failure in experiment. The electrician knows that he can scarcely be certain of successful experiments in a very moist atmosphere; for the aqueous vapour is condensed upon the surface of his instruments, and renders the most perfect insulator a good conductor. It is on this account that lecturers are so frequently unable to perform their experiments in damp or crowded theatres. But this source of electric dissipation may be in a great measure avoided by choosing such substances for insulators as most oppose the condensation of vapour on their surfaces. Glass is, in the majority of instances, found to be the most available non-conductor, but moisture is very readily deposited upon it. To avoid this, all glass used for electrical instruments and intended to insulate, should be coated with a solution of gum, which will generally be found an efficient preventive. In making Leyden jars and electrical stands, this is absolutely necessary.

It must also be mentioned that the form of the excited body will greatly influence the degree of dissipation. The sphere is the form best adapted for the retention of electricity, and it escapes most readily from points, especially if they project far from the surface. It is indeed almost impossible to accumulate electricity upon a body that terminates in a point.

If a metallic rod, having a spherical end, be placed in a situation to receive electricity from an excited body, its acquired electric state will be retained for a considerable time; but if a pointed wire be attached to it, the dissipation is so great that the electricity is conducted away as fast as it is received. If the conductor should be in a negative state, it will collect electricity with as great rapidity as it parted with it in the former case.

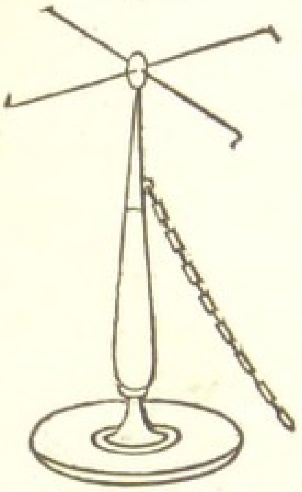
Upon the prime conductor of a machine place a pair of pith balls, as shown in fig. 1, and let the conductor be charged with electricity; its presence will be known by the divergence of the balls. Then bring near to the conductor a metallic rod with a spherical end, being careful not to take a spark, and it will take a considerable time to withdraw the electricity, or, in other words, to make the balls collapse. But if a pointed rod of the same metal be held at an equal distance, this will be very speedily effected.

Experiments with Points.

A number of interesting experiments have been invented to illustrate the principle of dissipation by points, some of which may be described.

Experiment 1. Take four metallic wires or arms, and fixing them into a brass centre or cup, let the opposite ends terminate in points bent horizontally in the same

Fig. 7.

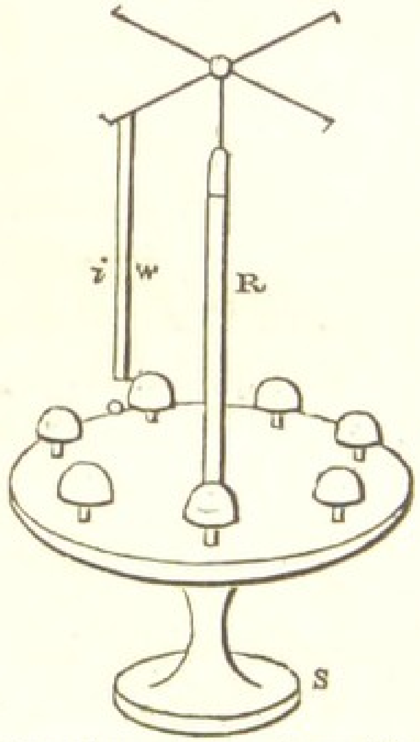


Experiment to show the action of points.

direction (fig. 7.), and support the arrangement upon a fine point, so that it may be balanced with tolerable accuracy. Connect this apparatus with the conductor of an electrical machine, and when it is electrified, the wires will revolve with considerable rapidity. This is occasioned by its giving off a a current of electricity, which produces a reaction of the air, and sets the arrangement in motion.

Experiment 2. By the use of the points, as described in the last experiment, a chime of bells may be played

Fig. 8.

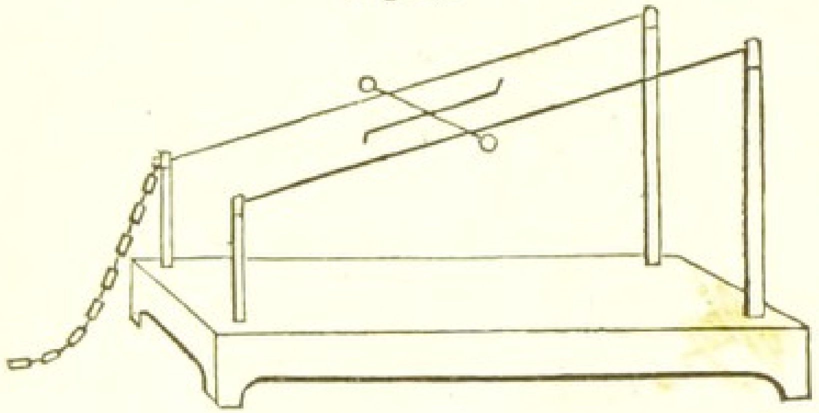


Experiment to show the passage of electricity from points, producing motion.

by electricity. (Fig. 8.) R is a glass rod fixed into a wooden stand, S, around which semicircular cups of bell metal are arranged. From one of the arms is suspended a brass knob, by a thread, *i*, which is kept in a steady position by passing through the bent part of a wire, *w*. Now when the points begin to revolve, the ball necessarily partakes of the motion and successively strikes the bells.

Experiment 3. The electrical inclined plane (fig. 9.) furnishes another experiment dependent on the action of points. Two wires are stretched in an inclined direction between four glass pillars. Upon

Fig. 9.



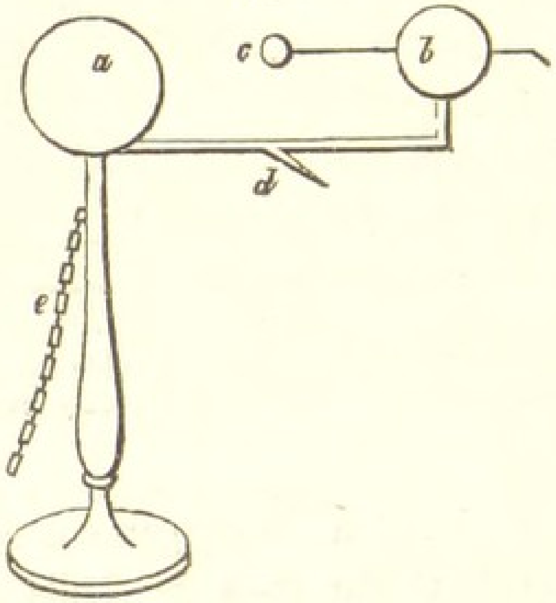
Experiment to show the revolution of a wire up an inclined plane produced by the passage of electricity from points.

these wires, is placed an arrangement consisting of a wire terminated at the ends by balls, with a cross piece at right angles having two bent points, as in the former experiments. According to the principles of gravity this loose wire can only roll downwards; but if a chain from the charged conductor of an electrical machine be attached to one side of the plane, the cross wire will roll upwards in consequence of the dispersion from the points.

Experiment 4. Figure 10 represents the electrical orrery, which furnishes another experiment dependent on the discharge of electricity from points. *a* is a large brass ball which rests on a fine metal point fixed to an insulating stand. To the ball, *a*, is attached an arm which carries at its opposite end a smaller ball, *b*, and through this is passed another wire, one end having a smaller ball, *c*, and the other terminating in a point.

d is a point fixed to the arm which connects *a* and *b*, and in the same plane. If the chain *e* be connected with the machine, and the system of bodies be electrified, the dispersion of the electric agent from the point,

Fig. 10.



The Electrical Orrery.

d, will cause the ball, *b*, which may represent the earth, to revolve round *a*, the sun, and the dispersion from the point attached to *b*, will produce the revolution of *c*, the moon, round *b*, the earth.

Electric Light.

Before we leave this branch of our subject, it may not be altogether unnecessary to remark, that when electricity passes from one substance to another through air or any other gas, light is produced. This branch of inquiry will be considered in another part of this volume, and only a few remarks will be now made.

Every substance is of course surrounded by air, which exerts a certain pressure upon it[1]. This must, therefore, be an obstacle to the passage of electricity from one substance to another when it intervenes between them, and the force exerted by the electricity in its attempt to escape must be greater than the pressure of the atmosphere before it can strike from one substance to another, through this resisting medium. On account of the opposing pressure of the atmosphere, and the extreme velocity of the electric fluid, the air is compressed by the electricity in its passage through it, and light is produced on the principle that occasions the same phenomenon when air is condensed by a syringe.

This theory was proposed by the celebrated French philosopher, Biot, to account for the production of luminous effects. But there are some electricians who have doubted the accuracy of this opinion, and believe that the light is occasioned by a peculiar property resident in the electric agent itself. But we are inclined to believe that M. Biot's opinion may be found sufficient to account for the phenomenon. It has been frequently proved that electricity moves with great velocity, and that the time required for its transference over a considerable space is too short to be measured. This being the fact, it must cause a very sudden compression of the air in its passage from one conducting substance to another. And as it is well known that a luminous appearance is the effect of considerable

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(1) See ALPHABET OF PHYSICS, page 77.

atmospheric condensation, the cause assigned by Biot for electric light, does not appear a very improbable assumption.

The Electrical Machine.

We have had frequent occasion to allude to the electrical machine as an instrument by which electricity may be developed in large quantities, and have mentioned some experiments which depend on its use. We are now in possession of facts sufficient for the explanation of its construction, and the principles of its action. It is sometimes made in one form, and sometimes in another, according to the fancy of the experimenter; but whatever shape may be given to it, the principle of its construction remains the same. The object to be attained by its use is the production of a large quantity of electricity, which is accomplished by exposing a large surface of a good electric to friction.

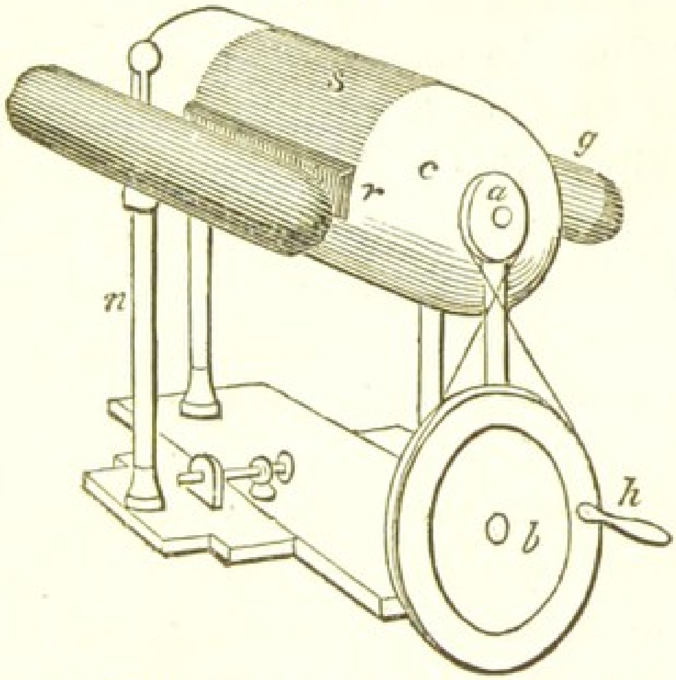
There are two kinds of electrical machines, the cylindrical and the plate; the construction of both we shall attempt to explain, without alluding to the minor varieties of form which are given to them by different makers.

THE CYLINDRICAL MACHINE.—(Fig. 11.)

c is a hollow glass cylinder supported on each end by a stand, and capable of a rotatory motion, which is communicated to it by a small wheel *a*, that is put into motion by a cord or catgut, uniting it to a large wheel *b*, turned by the handle *h*; *n* is an insulating stand, and supports a silk cushion or rubber, *r*, stuffed with horse-hair.

This cushion is made to press against the cylinder with a force which may be regulated either by a screw which brings the stand nearer to, or farther from, the cylinder, or by a spring attached to the back of the cushion

Fig. 11.



The Cylindrical Electrical Machine.

itself. On the upper edge of the cushion is fixed a piece of varnished silk, *s*, which covers the upper part of the cylinder.

g is an insulated brass cylinder with spherical ends, and is called the prime conductor. At that end of the conductor nearest to the cylinder there is a row of points which should be placed about half an inch from the surface of the cylinder.

As soon as the wheel *b* is put into motion, the smaller wheel begins to revolve, and with it the glass cylinder. By the rubbing of the glass against the cushion electricity is developed, and it is evident that the excitement is only a parallel case to that of the excitement of glass when rubbed with a silk handkerchief. But it is found that the amount of effect is greatly increased when an amalgam of zinc and mercury, formed into a paste with lard, is applied to the cushion. The silk flap prevents the dissipation of the electricity from the surface of the glass, and the fluid, being thus confined, is brought round to the points, which readily receive it, distributing it over the surface of the prime conductor. In this way the conductor may be charged with the electric fluid, and by any arrangement that may be adopted, the experimenter may carry it off from this reservoir, and employ it as he pleases.

The instrument that we have described produces positive electricity from the glass, and of course the rubber is in a negative state, for it has been already shown that when two substances are rubbed together, they are oppositely electrified. By removing the chain from the rubber and applying a conductor, the negative electricity may be obtained.

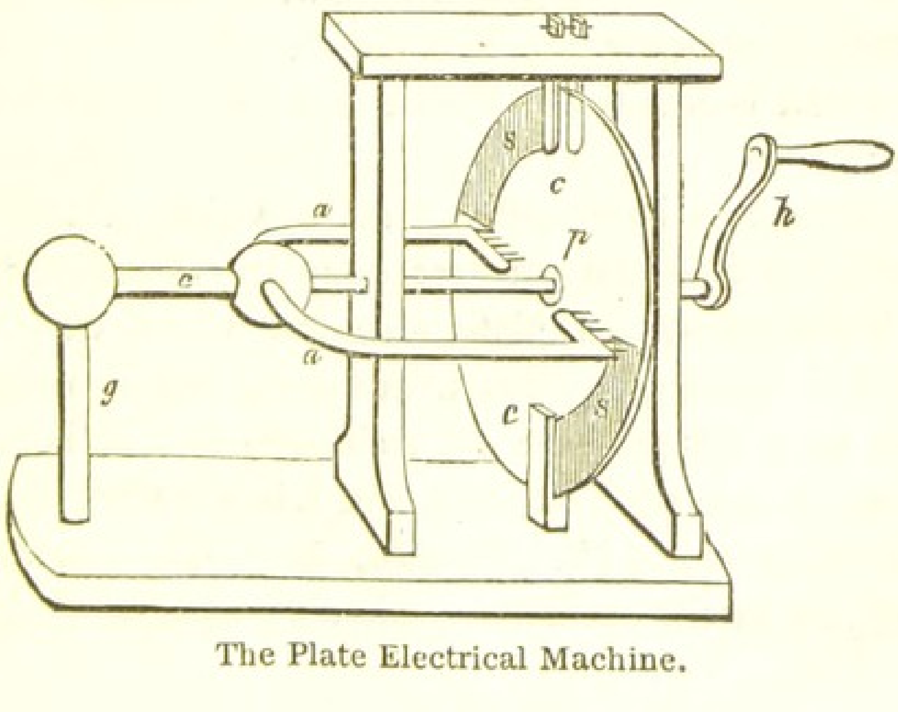
The first electrical machine was constructed by the celebrated Otto Guericke, of Magdeburg, the inventor of the air pump. It was formed by casting a globe of sulphur in a glass sphere which, when the sulphur had cooled, was broken, and the cast mounted on a revolving axis in a wooden frame. This rude machine was excited by the application of the hand.

In the year 1675, Sir Isaac Newton communicated to the Royal Society his important discovery, that excited glass as well as the resins would attract light substances. In the commencement of the eighteenth century, Mr. Hawkesbee constructed an electrical machine with a glass instead of a sulphur globe. M. Boze, professor of philosophy at Wittemburg, introduced the prime conductor. Professor Winkler of Leipsic employed a cushion for a rubber instead of the hand; and Gordon, a Benedictine monk, substituted a glass cylinder for the sphere.

Until the present day, this instrument has been receiving the attention of electricians; and the description we have given of it will show how much its construction has been improved. But we must not leave the electrical machine without a few remarks on that form, in which a plate is used instead of a cylinder, proposed by Dr. Ingenhouz, and since greatly improved by Cuthbertson and Woodward.

The plate machine consists of a circular plate, *p*, of glass, mounted vertically, so as to revolve on an axis.

Fig. 12.



The Plate Electrical Machine.

On opposite parts of the circumference of the plate, or rather at the top and bottom of the stand in which it is mounted, is fixed a pair of cushions, by which the plate is rubbed when put into motion. The pressure of these cushions is regulated by screws which cause them to press the plate with greater or less force. *c* is the prime conductor insulated by the glass leg *g*, and at the opposite end supported by the frame of the machine. *a a* are branching arms united with the conductor, and furnished at the end nearest the plate with a row of points, which collect the electricity from the surface of the excited body.

It is not necessary that any extended remarks should be made upon the action of this instrument, for it would only be repeating what has already been said in relation to the cylindrical machine. When the plate is put into revolution by turning the handle *h*, it is rubbed by the cushions *c c*, which action develops electricity, that is preserved from flying off the plate by the oiled silks *s s*, which extend to within a short distance of the points. The points collect the electricity which is conducted by the arms *a a* to the prime conductor *c*.

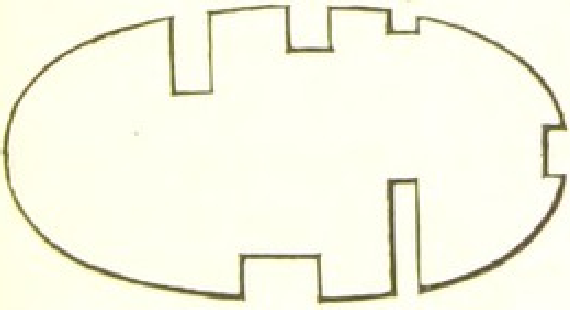
Philosophers have differed as to which of the two machines afford the greatest quantity of electricity; we believe that the plate machine, when well constructed, has greatly the advantage; but it requires great care, being liable to accidents, and it is more expensive than the cylinder. But it is a matter of little importance which kind be used, for if the instrument employed by the student be tolerably good of its kind, and be kept constantly clean, and well amalgamated, he may perform all the electrical experiments with it.

THE DISTRIBUTION OF ELECTRICITY.

It was observed by some of the earliest electricians, that the quantity of electricity received by a substance does not depend either upon its density or its bulk. Thus a solid metallic globe or cylinder cannot contain more electricity than a hollow one of the same size. From this fact it may be deduced, that the electric agent is not equally distributed through the mass, and it might be supposed that it is only distributed over the surface. This supposition is strengthened by the discovery that the quantity of electricity received does depend upon the extent of surface. To determine this problem, some of the most celebrated mathematicians commenced the investigation with the aid of the most accurate and refined of all reasoning, and have proved that when a body is excited, the electricity is only accumulated on the surface. In this result, theory and experiment agree; but our business is with the latter.

Coulomb, by a series of very delicate observations, proved the fact to which we have just referred. He took a conducting substance, and cut in it some small indentations (fig. 13.), those least depressed being not more than one tenth of an inch in depth. The substance was then insulated

Fig. 13.



Coulomb's experiment to prove that electricity is distributed over the surface of bodies.

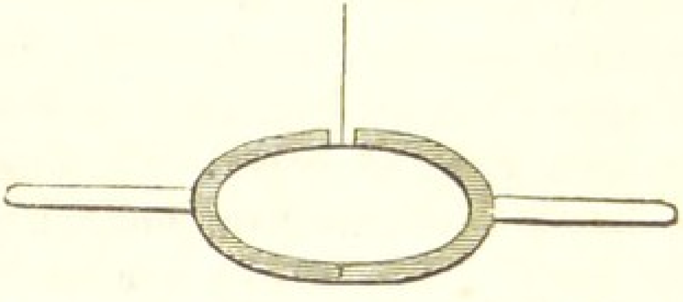
and electrified. The electric condition of these depressions was examined, and it was found that, although the surface gave proof that it was strongly electrified, they gave no indication of having had their electric condition at all disturbed.

M. Biot's Experiments.

M. Biot also made a series of very important and interesting observations on distribution. Two of his experiments may be mentioned, because they may be easily verified by the student.

His first experiment was to prove that when a solid substance is highly charged with electricity, it contains no more than can be carried away by a plate of the same superficial extent. The method in which this was performed is shown in fig. 14. A metallic spheroid,

Fig. 14.

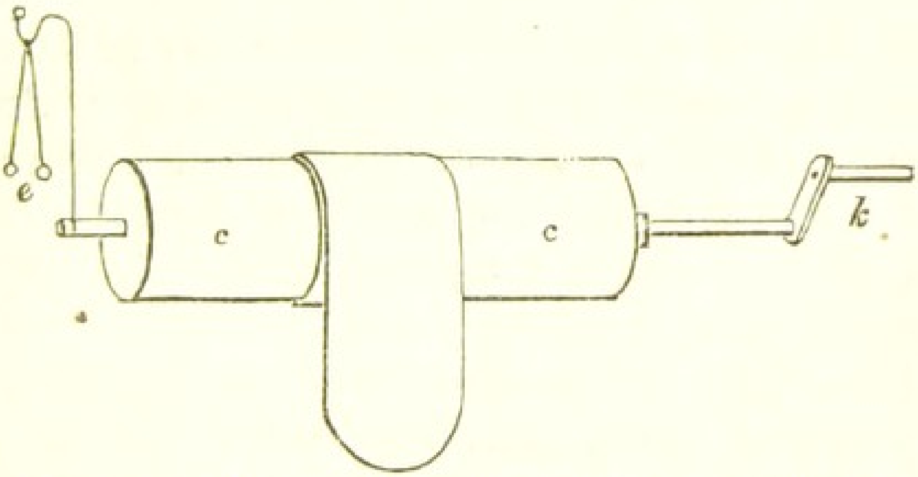


Biot's Experiment to prove that electricity is accumulated on the surface of bodies.

or a wooden one coated with tinfoil, was suspended by silk, or some other non-conducting substance; and two caps of thin tin with gum lac or glass handles were fitted to it. The ball was then charged with electricity, and the caps carefully placed over it, and, however highly the spheroid might have been electrified, it was found to have entirely lost its electricity when the caps were removed.

The second experiment (fig. 15) leads us to another deduction. *c c* is an insulated cylinder capable of rota-

Fig. 15.



Biot's Experiment to prove that electricity is accumulated on the surface of bodies.

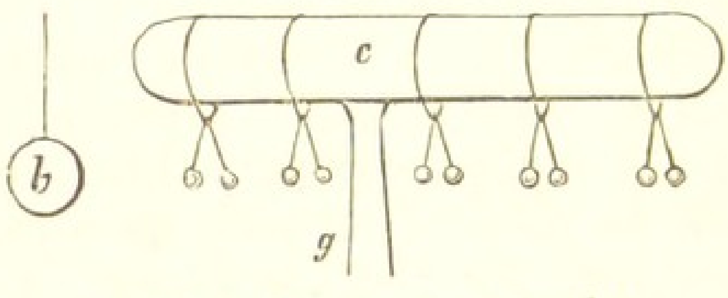
tion by a handle, *h*. Round the cylinder is coiled tinfoil fastened to it at one end, and at the other having a silk thread, by which it may be unrolled. To this apparatus is attached a pith ball electroscope, *e*. Let us suppose the tin-foil to be coiled up. Charge the cylinder, and the pith balls will diverge. If the tinfoil be now unrolled, the pith balls will begin to collapse, and, should its surface be equal to the surface of the cylinder, they will come in contact. From this experiment we learn that the electric agent is only distributed over the surface of substances.

Electric Induction.

Hitherto we have spoken of the disturbance of electric equilibrium produced by either the excitement of the substance or by the conduction of the electric agent from an excited substance. But there is another source of electrical disturbance, to which we must refer. Whenever an excited substance is brought into the vicinity of substances in their natural condition, it tends to produce in them an electrical state opposite to their own, and this it does however perfect may be the insulation; in fact, without any communication of electric agency. Thus, a substance charged with positive electricity will influence any substance situated near it, and cause it to have a negative state. This effect is therefore called influence or *induction.*

The nature and consequences of this singular action will perhaps be best illustrated by the mention of an experiment (fig. 16). Let *c* be a cylindrical conductor

Fig. 16.



Experiment to illustrate induction.

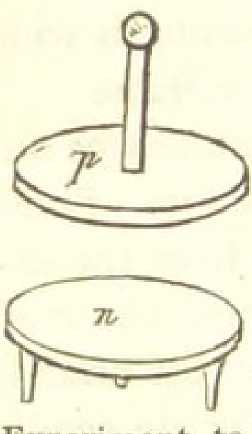
with hemispherical ends resting upon an insulating stand, *g*, and let the conductor be furnished with a series of pith ball electroscopes, suspended from it by linen threads. Now bring near to this unelectrified cylinder an electrified ball, *b*, being careful that there shall be no conduction, and the electrometers at both ends will show the presence of electricity, although no electricity has been communicated, by the divergence of the balls. But the amount of divergency decreases from the ends to the middle, where a point may be found at which the balls remain uninfluenced. This point varies with the distance of the conductor from the electrified substance. It now becomes an object to determine the condition of the diverging balls, whether they be charged positively or negatively. Let us suppose that the body, *b*, contains positive electricity. Then take a glass tube and excite it with a piece of silk, and it will be charged with positive electricity. Now if the excited glass be brought near to the diverging electrometer nearest to the ball, *b*, it will attract it, which proves that the balls of that electrometer diverge with negative electricity, the glass being positive. It will also be found that all the pairs of balls on the side nearest to the ball, *b*, diverge with negative electricity, while those on the opposite side have the same effect produced with positive. Now remove the excited substance, *b*, or carry off its electricity by touching it with the finger, and the pith balls immediately collapse.

From the experiments we have just enumerated we may learn the influence of electrical induction. Since there is no communication of electricity from the excited substance to the cylinder, the phenomena observed must result from an influence exerted upon the natural electricity; and since the two opposite electric conditions may be made to appear or disappear by the introduction or withdrawal of the excited substance, they must result from its influence. The excitement therefore of electricity in any body tends to induce an opposite state in the substances that are near it. But as there is no actual communication of or parting with electricity in the substance, so it is impossible to induce one state of electricity on one part of the surface without producing the other state on the other opposite part. Thus in the experiment just described, the positively electrified substances, *b*, induces a negative or minus state in that end of the cylinder nearest to it, and this cannot of course be done without at the same time producing a positive state on some other part, and we consequently find that the end of the cylinder most distant from the excited substance is positively electrified.

Induction applied to the accumulation of Electricity.

Take two circular metallic plates, *p* and *n* (fig. 17), and placing them one above the other with a non-conducting medium, as air or glass, between them, connect the upper one, *p*, with the prime conductor of a machine, the lower one, *n*, being insulated. Now charge *p* with positive electricity, and upon the principle of induction, the electricity naturally contained by *n* will be repelled, and the upper surface of that plate will be left in a negative state, while the lower will be positive. This change being effected, establish a communication between the lower surface of the plate, *n*, and the ground, and the accumulated electricity will be carried off, leav-

Fig. 17.



Experiment to illustrate the principles of induction.

ing the plate with less than its natural quantity of electricity. But before making this communication, place a quadrant electrometer on the prime conductor, and it will be seen to fall as soon as the contact is formed. This proves that a portion of the electricity contained in the conductor is also carried away at the same time, but it can only be conducted to the upper plate, *p*; and this actually occurs, for the abstraction of electricity from the lower plate calls into action some force which accumulates the electricity in the positive plate, *p*. If the prime conductor of the machine be again charged, and the same course of experiment be adopted, the same results will be observed.

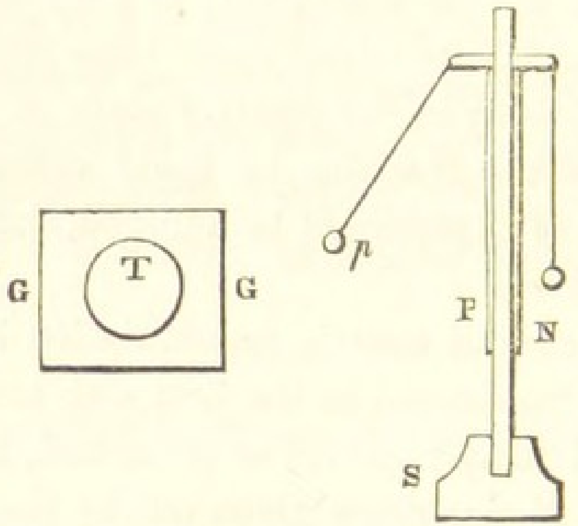
This is a case of electric accumulation by induction, and may be considered as the first step towards a practical plan. It may however be remarked, that although the amount of electricity given out by the lower plate, cannot be equal to the amount of that with which the upper one is charged, the quantities become more equal as the distance between the plates is decreased, the actual transfer of the electricity being of course prevented by the intervention of a non-conducting substance.

It is evident then that the process of induction is not interfered with by the presence of a non-conducting substance, that is, a substance whose own electrical condition will not be greatly influenced by the presence of an excited body. On this account it was proposed that the most convenient method of accumulating electricity by induction would be to employ glass coated with tin-foil, a sufficient margin of uncovered glass being of course left in order to prevent the transfer of electricity from one side to the other.

An experiment analogous to that last described may be made with an apparatus constructed in the following way.

Let a plate of window glass, G G, be coated with

Fig. 18.



Experiment to show the accumulation of electricity by induction.

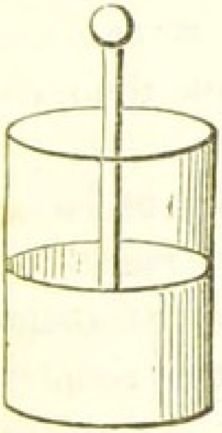
tin-foil, T, sufficient margin of glass being left to prevent transfer. Fix this vertically (fig. 18) in a wooden stand, S, and let each side be furnished with a pith ball. If the coating, N, communicate with the ground, and P be charged positively, the ball, *p*, will rise from the surface of the plate, showing its excited state, and, according to the principles of induction, the surface, N, will part with its electricity through the conductor to the ground in proportion as the electricity is accumulated on the opposite surface.

If now a communication be formed between the two coatings by a conductor,—a metallic wire, for instance,—the accumulated electricity on the surface, P, will rush along the wire and supply the place of that which had been lost from the surface N. There are certain effects produced upon the substances through which the electricity passes under these circumstances, as the production of light in passing through air, and the excitation of the muscular system when conducted by the animal body ; but of these we shall speak in another place.

The Leyden Jar.

The most convenient instrument for the accumulation of electricity is a glass jar coated with tin-foil, called a Leyden Jar, because invented at Leyden in Holland. To construct one of these, take a plain glass jar (fig. 19.), and upon the exterior and interior surface paste tin-foil within a distance of the top sufficient to prevent the electricity from passing from one surface to the other. To the jar is generally fitted a wooden cover, and in this a metal rod is fastened, which reaches two or three inches above the top, terminating in a ball, and is commonly connected with the interior coating by a chain hanging loosely from its interior end.

Fig. 19.



Experiment to show the use of metallic coatings for the accumulation of electricity.

Take a jar thus prepared, and bring the knob near to the prime conductor of an electrical machine in action, and a series of sparks will be observed to pass between them, a proof of the circulation of the electric agent. When the sparks become feeble, or entirely cease, the jar is charged, and the experimenter cannot continue to expose the knob to the passing agent without danger of breaking his jar. This will afford him a proximate method of determining when the jar is charged, but the quadrant electrometer should be employed for this purpose when large jars are used. If, when the jar has been thus charged, a person should take the exterior coating in one hand and touch the ball with the other, he will experience a shock, that is, a convulsive motion, in the joints and muscles, attributable to the passage of the electricity through him. If a series of persons, holding hands, and thus forming a chain, should receive the shock, it will be felt by each individual. This experiment may be made by the person at one end holding the jar by the exterior coating, while the individual at the other end touches the knob.

Here, then, we have an instance of the accumulation of electricity, and it is scarcely necessary to remark that it is done by induction, and is an experiment analogous to that described in a former part of this chapter. Electricity is communicated to the interior surface, which renders it positive; by induction the exterior becomes negative, a portion of its electricity being driven off and conducted away through the person when held in the hand, or by any conducting substance on which it may rest.

There are two circumstances upon which we remarked, when speaking of the principles of induction, which may be exemplified by experiments with the Leyden jar: first, that the accumulation by induction cannot go on without one of the surfaces be in conducting communication, and secondly, that the power of accumulation will rapidly decrease as the thickness of the non-conducting substance increases.

Experiments with the Leyden Jar.

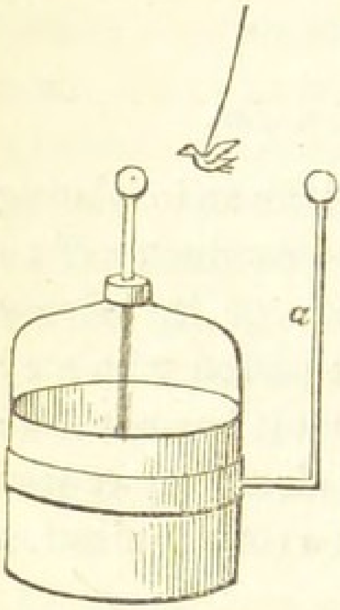
1. Take a Leyden jar, and placing it on an insulating stool, bring the ball near to the excited conductor of an electrical machine, and attempt to charge it. Every effort will be found useless, and any person who may attempt to receive a shock will find that it has not been charged. Hence it will appear that electricity cannot be accumulated by induction without a communication between one surface and the ground.

2. If two Leyden jars be taken, of equal size, and having the same amount of coating, one being formed of thin and the other of thick glass, and a charge be given to both, the thin jar will receive a much more powerful one than the thick. It is necessary that the jars should be of a certain thickness, for there is a point of accumulation at which the force of attraction between the electricity of the surfaces would be sufficient to force a passage through glass of less substance. The amount of thickness required has been determined by experiment, and proper jars for electrical purposes may be easily obtained by purchase. But if the danger to which we have alluded be guarded against, the thinner the glass the more intensely may the jar be charged.

The observations that have been made involve the statement that the exterior and interior coatings of a Leyden jar are in opposite electrical states. This may be proved by two or three experiments.

Exper. 1. Take a large Leyden jar, and bind round its exterior coating an iron hoop supporting an arm, *a*, at the end of which is fixed a ball rising to the same height above the mouth of the jar as the knob which communicates with the interior coating (fig. 20). Then charge the interior coating with positive electricity, and it will be found that the exterior is negative. To prove this, take a pith ball or bird, and suspending it upon an insulating stand, midway between the knobs of the jar, it will be alternately attracted and repelled by each, till the jar is discharged by its silent conduction of the positive electricity to the exterior coating. This is a result which could only be the consequence of an opposite electrical state between the exterior and interior coating.

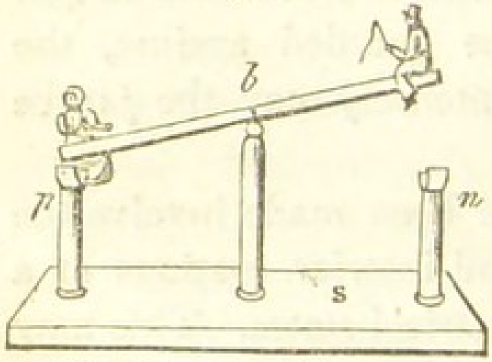
Fig. 20.



Experiment to prove that the coatings of a Leyden jar are oppositely electrified.

Exper. 2. Figure 21 represents a philosophical toy called the Electrical See-saw, which affords a good illustration of the fact that the opposite coatings of a Leyden Jar are in opposite electrical conditions. *p* and *n* are glass rods fastened into a stand *s*, the upper ends being furnished with a brass knob.—*b* is a lever delicately suspended in the centre, so as to have a freedom of motion. The under surface of the lever is fur-

Fig. 21.

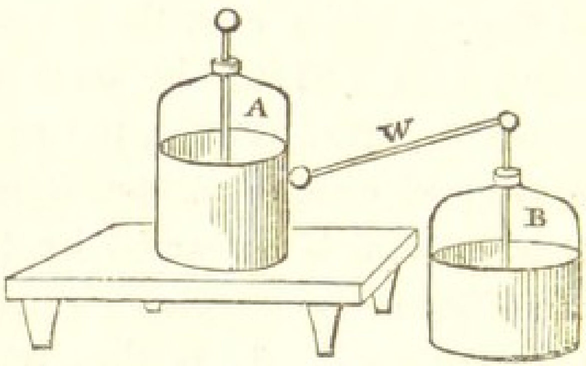


The Electrical See-saw.

nished with a strip of tin-foil so as to form a conducting communication between itself and the balls. At each end of the lever a paper figure is pasted. Now, let the knob of *p* be connected with the inside of a charged jar, and that of *n* with the exterior. The knob *p* is now charged with electricity in the same state as the interior of the jar, and *n* is in the same state as the exterior coating. One end of the lever will preponderate and touch the ball, as at *p*, but as soon as it is put into the same electric condition, it is repelled by the ball it touches, and is attracted by the other, to which it communicates its surplus electricity, and is put into a negative state. It is then repelled by the ball *n*, and is attracted by *p*. In this way a constant motion will be kept up until the jar is discharged. This experiment is a good illustration of the fact that the exterior and interior coatings of a Leyden jar are in opposite electrical states, one having more, the other less, than its natural quantity of electricity; for it is only by the admission of this fact that the motion can be accounted for.

Both the principles of which we have spoken are illustrated by another experiment, which, on this account, is worthy of notice. Take a Leyden jar A (fig. 22) and insulate it by placing it on a glass-legged stool. With the exterior coating connect the interior coating of another jar, B, by a conducting wire W. Then, by uniting the knob of the jar A with the conductor of an electrical machine, it will be charged positively, and the jar B will be also charged. The cause of this is evident. When there is no conducting communication between the exterior coating and the earth, a jar cannot be charged, for there is no means of passing off the electricity. But in this experiment, the electricity is carried away by the conductor, and thus the second

Fig. 22.



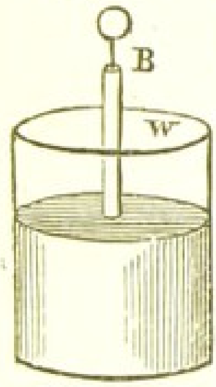
Experiment to prove that there must be a conducting communication from one surface of a Leyden jar.

jar is charged positively, its outer coating being in communication with the ground. In this experiment we have not only a proof that a conducting communication from one surface is absolutely necessary, but also that the coatings are in a different electrical condition; for, were not this the case, the jar B could not be charged with positive electricity. This last fact may be tested in other ways, and the similar nature of the charge in both jars may be experimentally proved; for, if an insulated pith ball be suspended between the knobs of the two jars, it will be attracted by both, flying to that which has the greatest attraction; but as soon as it has received a charge of electricity by contact, it will be repelled by both knobs.

One other question, relating to the Leyden jar, remains to be answered. What is the use of the metallic coatings? It may be supposed that the electricity is necessarily accumulated on the coatings; but this supposition is erroneous, as may be proved by a single experiment.

Take an open glass jar (fig. 23) and fit it with moveable coatings of thin tin plate. *W* is a wire passing through a glass tube, connected at one end with the interior coating, and at the other with a brass knob *B*, which reached three or four inches above the rim of the jar. Charge this jar in the usual manner, and place it upon an insulating stool. Lift out the inner coating by the glass tube W, and then, taking hold of the outer coating, turn the jar upon its mouth, and remove that also. Both the coatings may now be touched without producing a shock, or giving any proof of the presence of electricity; but let them be replaced, and the jar may be discharged as though they had not been removed. From this experiment it is evident that, in the Leyden jar, electricity is accumulated on the surface of the glass, and the coatings act merely as conductors, collecting the diffused electricity to one place at the moment of discharge.

Fig. 23.



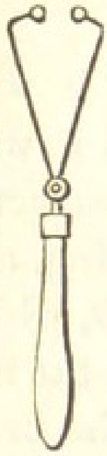
The Leyden Jar.

Discharging Electricity.

A few words may, perhaps, be necessary on the method of discharging the jar, which should be done with great care, particularly when powerful charges are employed.

The discharging rod (fig. 24) is commonly employed to discharge the Leyden jar. It consists of two bent metallic arms connected at one end by a joint, the other ends terminating in brass balls. By this arrangement the balls may be made to approach each other, or may be separated in the same manner as a pair of compasses. A metallic socket is connected with the joint, and a glass handle is fixed into it for insulation.

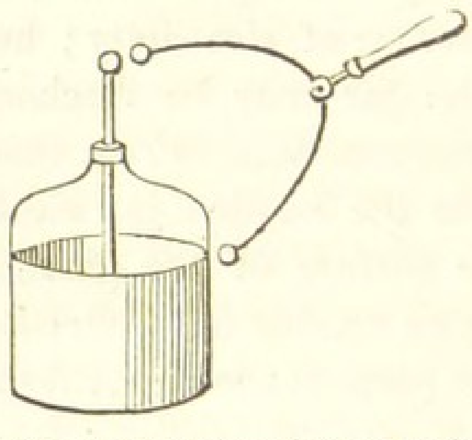
Fig. 24.



The Discharging Rod.

When it is required to discharge a jar, the arms are separated to such a distance that one ball may be in contact with the conducting wire of the interior coating, while the other is in contact with the exterior (fig. 25). As soon as the contact is made, the accumulated electricity rushes from the positive surface to the negative, and thus establishes the equilibrium.

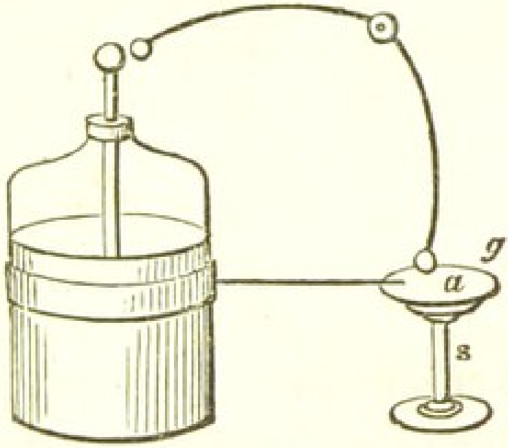
Fig. 25.



The method of discharging a Leyden Jar.

But it is often required that the electricity, in passing from one surface to the other, should be conducted through a particular substance, on which we expect it will produce some effect; that is, in technical terms, the substance must form a part of the electrical circuit. Thus it may be required to pass the electricity through a detonating compound. Let us then take a jar (fig. 26)

Fig. 26.

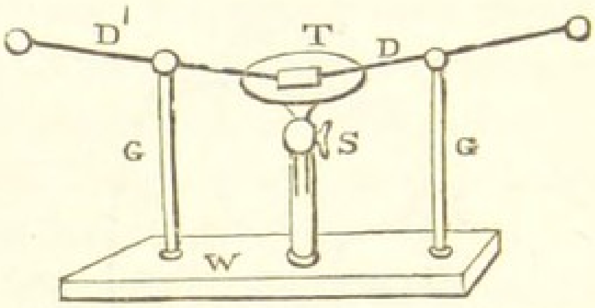


The method of discharging a Leyden Jar through any substance.

and charge it, the interior being positive. The detonating compound we will place on a non-conducting substance, a piece of glass *g* on an insulating stand *s*, for example. In order that the electricity, accumulated on the inner surface, may pass through this compound in its passage to the exterior surface, we will connect the latter with the substance, by means of a metallic chain. Then with a discharging rod we connect the interior surface with the opposite end of the substance, so that the electricity in passing along must enter and traverse the substance. In this way any body may form part of the electric circuit, and we may determine the influence of the accumulated electricity upon it.

When it is requisite to pass the charge with great precision, Henley's universal discharger may be used with advantage. This instrument is represented in figure 27.

Fig. 27.



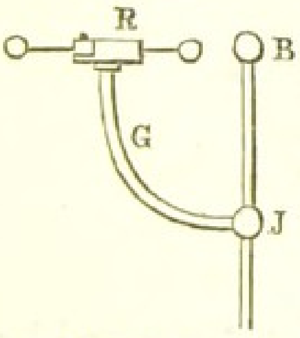
The Universal Discharger.

W is a wooden stand, and *T* an ivory table fitted to it, and capable of being raised or depressed by moving in a socket, and may be fixed at any height by the screw *S.* *G G* are glass pillars, and on the top of each is fitted a joint capable of either a horizontal or a vertical motion, and upon this joint is fixed a spring tube which receives the metallic rods or directors *D D*, which terminate with points, on which are fitted balls that may be removed at pleasure; some experiments requiring the one, and some the other. Supposing a substance to be placed between the balls of the directors, the charge may be passed through it with certainty. Let *D* be connected with the exterior coating by a chain, and *D'* with the outer coating by a discharging rod, a conducting path is thus formed for the passage of the electricity, and it must pass through the substance to be experimented on before it can reach the negative surface of the jar.

Two or three instruments have been invented, having the double object of discharging a jar, and of measuring its electricity; and, although we are convinced they cannot be employed with safety, yet it is necessary to describe them, as they are usually classed among electrical apparatus, and are recommended by some writers.

Lane's Discharging Electrometer (fig. 28) is an instrument of this kind. B is a ball connected with the interior coating of a Leyden jar, and J is a socket ball fitted to the wire that connects B with the interior coating. R is a short metallic wire, supported by the bent glass rod G, and moves in a tube so as to admit of the adjustment of the knobbed wire at any distance from B that may be required. This instrument is sometimes used by fearful and inexperienced men, that a jar may discharge itself. The rod R is connected with the exterior coating of the jar, and then as soon as the electricity has sufficient power to strike through that portion of air which intervenes between B and the knob, the electricity is conducted from the positive to the negative coating. We can scarcely imagine an instance in which the discharging electrometer can be necessary; but if there should be one, it must be that in which it is required to have a succession of discharges of a particular strength, which may be obtained by arranging the distance between the two balls.

Fig. 28.



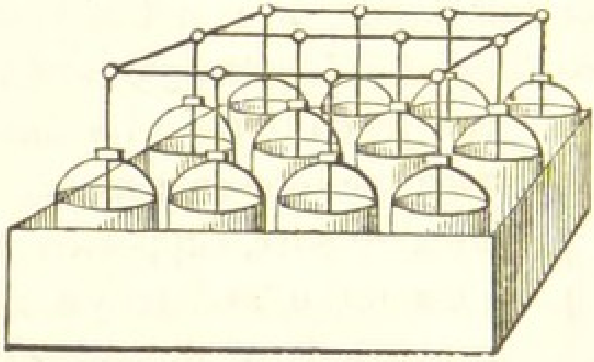
Lane's Discharging Electrometer.

The Balance Electrometer, invented by Cuthbertson, is an instrument formerly used as a self-acting discharger, but that is now seldom, if ever, employed, and consequently need not be described in this volume.

Electrical Battery.

When two or more Leyden jars are united, they constitute an electrical battery (fig 29). For this

Fig. 29.

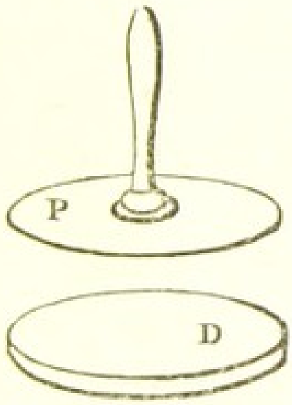


The Electrical Battery.

purpose all the interior coatings must be connected by metallic rods, and the exteriors may be made to communicate by placing them on a sheet of tin-foil. They are generally arranged in a wooden box, each jar being separated from the others by light partitions. The bottom of the box is coated with tin-foil, to ensure a direct communication between the exterior surfaces of the jars, and with the tin-foil a chain or wire is connected, and brought to the exterior of the box. The interior surfaces are connected by wires, as shown in the figure. By this arrangement any number of jars may be united together, and made to act as a single one. Large charges may be thus accumulated, but as the instrument is liable to a spontaneous discharge, the quadrant electrometer should always be used, and great care should be taken by the experimenter, as the discharge of a large battery through his own person would be attended with serious consequences.

Before we close our remarks upon the accumulation of electricity by induction, we must describe an instrument called the Electrophorus (fig. 30), invented in the year 1774 by the celebrated Professor Volta. D is a tin plate, or, what is still better, a dish or mould, into which is cast some resinous substance*. P is a metallic plate, to the upper surface of which is fixed a glass handle for insulation. Excite the resinous plate by beating or rubbing it with fur or flannel; by this means it will be negatively electrified. When this has been done, take the plate by its insulating handle and place it upon the excited resinous surface. From the tenacity with which the resin retains its electricity, the contact of the plate with it is not sufficient to abstract its electricity, but the principle of induction is called into action. The surface of the metal plate or cover that is in contact with the resin acquires a positive state, the resin being negative, and the upper surface is of course in an opposite condition to the lower. If, while the plate is in this situation, the upper surface be touched by the finger, or some other conductor communicating

Fig. 30.



The Electrophorus.

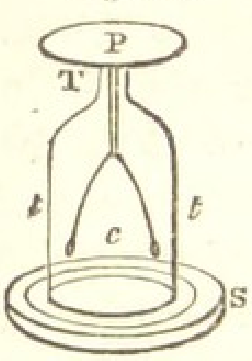
* Equal quantities in weight, of shell-lac, resin, and Venice turpentine, melted together, will form the best compound for the resinous plate.

with the earth, it will abstract sufficient electricity to restore the equilibrium between the two surfaces. When the plate is raised from the resinous body by the insulating handle away from the inductive influence of the excited substance, it will of course be charged with positive electricity, which may be imparted to a Leyden jar or any conductor. By successive contacts a jar may be charged, and as no electricity is carried away, the cover, when once excited, will remain in that state for a long period. We were once greatly surprised to find an electrophorus, that had not been used for six months, in vigorous action.

This capability of retaining its electric excitement renders it an useful instrument to the chemist, and causes it to be often employed in the laboratory for the explosion of gases.

We are now in possession of sufficient information to understand the action of a very beautifully contrived instrument, called the Gold-leaf Electroscope (fig. 31), invented by Mr. Bennett. It is generally employed to detect the presence of minute quantities of electricity, and to determine whether it be positive or negative. *c* is a glass cylinder, into the top of which is fitted a glass tube T. Through the centre of the tube is passed a metallic wire, in connection at the top with a brass plate P, called the cap, and having two narrow slips of gold leaf attached to the other end, hanging parallel to each other. *t t* are slips of tin-foil pasted on the inside of the cylinder, in such a position

Fig. 31.



The Gold-leaf Electroscope.

that should the gold-leaves strike against the sides, they may come into contact with them. s is a wooden or brass stand, with which the tin-foil is in contact; the object of this arrangement will be evident, when we have enumerated a few experiments that may be made with the instrument, which will perhaps be the best way of explaining its action.

Experiments with the Electroscope.

Experiment 1. Excite a stick of sealing-wax with a piece of woollen cloth or flannel, and it will be negatively electrified. While the wax is thus excited, touch carefully the cap of the electroscope, and the gold-leaves, with which it is in conducting communication, will have part of their electricity abstracted. But as any two substances in the same electrical state repel each other, the gold leaves, being charged with negative electricity, will repel each other. Touch the cap with the finger, and the equilibrium will be restored, and the leaves converge.

Experiment 2. Excite a piece of sealing-wax by rubbing it with flannel, and bring it near to the cap of the electrometer, being careful that no electricity be positively conveyed from the wax to the electrometer. When the excited body is at such a distance from the electrometer as to forbid the supposition that there is any transfer, the leaves will begin to diverge, and will remain in that state so long as the excited body be near them. This is the result of that principle which is called induction, and is an illustration of the statements we have already made.

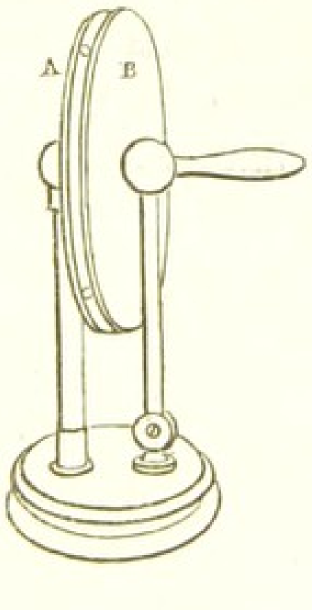
Experiment 3. Take a piece of excited sealing-wax and touch the cap of the electrometer with it, being careful that the charge be not too strong, or the leaves will be repelled to such a distance from each other as to cause them to touch the sides of the glass, which frequently breaks them. The leaves being charged by contact with the electricity of sealing-wax, or, in other words, being negatively electrified, excite a piece of glass and bring that near to the cap of the electrometer without touching, and the leaves will contract, proving that the electrical condition of the leaves is different from that of the body which is brought near to them. The same effect would of course be produced if the leaves diverged with positive electricity, and a body in a negative state were brought near.

The student must at once perceive the importance of this last experiment upon all his inquiries into the electric condition of bodies. By this means he can always determine whether a body be positively or negatively electrified, and with the assistance of the condenser the weakest electrical state may not only be rendered apparent, but may also be examined. Suppose we have found a mineral, and require to know what would be its electrical condition when rubbed with any particular substance, we may then cause the leaves to diverge with positive electricity, by touching the cap of the electrometer with a piece of excited glass. The mineral is then excited, and made to approach the cap of the electrometer; if the leaves converge, the mineral is in a negative, if they diverge, it is in a positive state.

In this manner the student may prove all the statements that have been made in relation to the influence of colour and texture upon the electricity of a substance, and the circumstances under which electricity is developed. Thus, if a black and white silk be rubbed together, one will be positive, the other negative. If a tin saucer, containing water, be placed upon the cap of the electrometer, and a hot cinder be dropt into it, the leaves will diverge. Hence we know that electricity is given off during the vaporisation of water, and the kind of electricity with which the leaves diverge may be determined by bringing an excited body near to the diverging leaves.

An instrument called a condenser (fig. 31 *a*) is

Fig. 31 *a.*



sometimes used with the gold-leaf electrometer. This instrument, invented by Volta, is used when it is necessary to examine the nature of feeble electricities. It consists of two metallic plates, one of which, A, called the receiving plate, is supported by a glass leg, while the other, B, called the condensing plate, is supported by a brass rod having a joint at the bottom, so that it may be removed to any distance from the plate A. Let the plate A be connected with the gold-leaf electroscope by means of a piece of metal wire passing from the ball of that plate to the cap of the electroscope, and the presence of the plate B, which communicates with the earth, will condense upon A, a much larger quantity of electricity than it could otherwise receive. Remove the electrified body from the plate A, and withdraw the plate B, and the electricity it contains will be partly removed from the surface, and communicated to the gold leaves of the electroscope for examination. This instrument is almost indispensable to the examination of weak electricities, such, for instance, as that developed by heating mineral substances. The condenser is made in various forms to suit the convenience or humour of the experimenter.

EFFECTS OF ELECTRICITY.

We have now detailed and explained some of the most obvious phenomena which result from the accumulation and motion of electricity; but our attention has hitherto been chiefly directed to circumstances which relate to the agent itself. We have spoken of its transference through bodies, but no notice has been taken of the influence it exerts upon the bodies through which it passes; and we have also described the methods by which it may be accumulated, but no allusion has been made to the effects produced by accumulated electricity on the substances through which it passes. Except in the phenomena of attraction and repulsion, the attention has been confined to the agent itself; we will now attempt to explain its influence upon substances.

Electricity has no influence upon bodies, save by attraction and repulsion, when at rest, how much soever it may be accumulated; but, as soon as it is put into motion, some effect may be expected to result. Charge a large jar, and as long as the accumulated electricity is retained by it, no visible effect is produced; but allow it to pass through a magnetic needle, and it will destroy the polarity; allow it to pass through a small metal wire, and it will raise its temperature. This is the class of effects to which we allude, and of which we shall treat in the following order:

1. Magnetic effects.
2. Luminous effects.
3. Heating effects.
4. Chemical effects.
5. Physiological effects.
6. Mechanical effects.

MAGNETIC EFFECTS.

In considering the effects of electricity upon substances, we may first direct our attention to its influence upon those which possess the magnetic property, and those in which the magnetic force may be induced. Some of the earliest experimenters indulged a vague notion that there was some intimate connexion between the cause of electric and magnetic phenomena; while others pronounced them to be identical, from the examination of certain fancied or real analogies. Pleased with the boldness of the generalisation, they satisfied themselves with contemplating the results of the identities they had fancied, and speculating upon the grandeur of the discovery if it could only be made. The mind, which is too apt to be satisfied with its marauding excursions into the regions of fancy, was thus debilitated, and rendered unfit for an examination of the regions of philosophical truth. The strongest minds were enervated by the opiate influence of this personal satisfaction; and the experimental process of investigation was, in this instance, abandoned for the less laborious musings of the study. Such was the state of philosophical opinion in the last century on this subject, and it is almost unnecessary to say, that but little was done towards the investigation of the magnetic effects of electricity. In the year 1819, Professor Oersted discovered that voltaic electricity has an influence on the directive force of the magnet,[1] a discovery which has led to so wide a field of examination, that the attention of modern philosophers has been greatly drawn away from the subject of common electricity, and we are, at the present day, almost as ignorant of its magnetic effects as were the philosophers of the eighteenth century.

The magnetic effects of common electricity may be classed under three heads: it may cause a momentary deviation of the needle from the magnetic poles; it may destroy the directive force of the magnet, and it may give the magnetic property to substances containing iron. All these have also been produced by atmospheric electricity, the presence of which is made known by the phenomena of thunder and lightning, which are the effects of its transmission. When Franklin was studying the analogy between the operations of atmospheric electricity and that of the electrical machine, his attention was necessarily drawn to a consideration of its magnetic influence. We shall here, therefore,

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(1) See Alphabet of Voltaic Electricity.

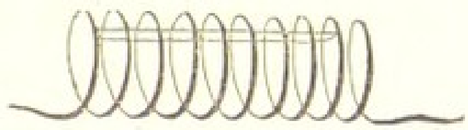
allude to both these sources of electricity, since they have been proved by Franklin to be identical.

Effects on Polarity.

When accumulated electricity is made to pass through a magnet, it destroys or changes its directive power.

If a magnet be placed in a helix (fig. 32), and a

Fig. 32.



Experiment to show that the passage of accumulated electricity through a magnet will destroy its polarity.

charge be passed through it, the polarity will generally be entirely destroyed, a greater or less degree of accumulation being required, according to the size of the magnet. But this is not invariably the result; for it is sometimes found that the poles are reversed, or otherwise changed, the magnetic property remaining. The same effects have frequently followed thunder storms, and we have many instances of this on record. In the Philosophical Transactions (vol. xiv.), it is stated that the ship Alexander, when about 100 leagues from Cape Cod, in latitude 48°, encountered a violent thunder storm, which reversed the poles of all the compasses in the ship, a circumstance not discovered until the following night, when it was found by the commander that he had steered in a direction exactly opposite to that which he had intended.

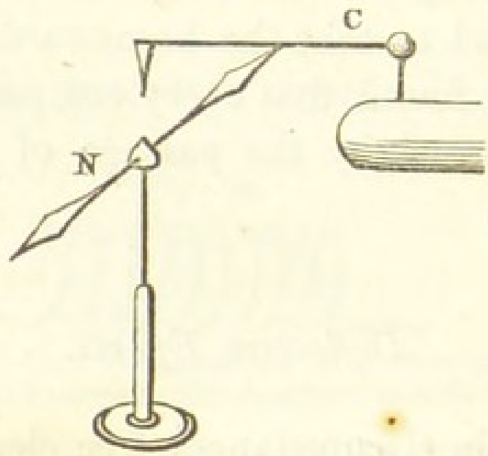
In the Philosophical Transactions (vol. xi.) a similar circumstance is mentioned. It appears that two vessels, in company on a voyage to Barbadoes, were, in the neighbourhood of Bermuda, in a violent thunder storm. One of the vessels was struck, and the fore-mast and sails considerably damaged. As soon as the storm had passed, the vessel was seen by those in the uninjured vessel to take the homeward course, and it was afterward found that every compass in the vessel had been reversed by the passage of the electricity through them.

Deflective Effects.

Under certain circumstances free electricity has the power of causing a deflection of the magnetic needle from the magnetic meridian. M. Colladon, of Geneva, was the first who succeeded in producing this effect, and described his experiments in a memoir read to the Academy of Sciences in the year 1826. Dr. Faraday has recently confirmed these results. In the experiments of both these celebrated philosophers, strong charges were employed, and it was found that whether the charge was passed through air, water, or an exhausted receiver, the same results were obtained; but the experiment succeeded better when imperfect conductors were used, from their having the property of converting a powerful charge into an almost continuous current.

The same results, however, may be obtained under very different circumstances; for Mr. Woodward has proved that the deflection may be produced by a breeze of electricity, which is a current of electricity issuing from the electric machine through a point situated at some distance from the substance to be affected, as is shown in figure 33. N is a magnetic needle delicately

Fig. 33.



Arrangement to show the Deflection of the Magnetic Needle by a breeze of electricity.

balanced on a point; a conductor, C, which may, by means of a joint, be placed at any distance from the needle that may be required, is connected with the prime conductor of a machine, and a current of electricity is transmitted from it which causes the deviation of the needle from its true position.

This experiment appears to us almost analogous to the effect of the aurora borealis. It is well known that this phenomenon, frequently observed in the northern regions, derives its origin from the passage of electricity in the higher parts of the atmosphere where the air is in a very rarefied state. The aurora is well known to produce a disturbance in the directive power of the needle, and to cause a perpetual state of agitation during its presence, varying as much as three, four, or five degrees; a phenomenon first observed by Professor Wargentin in 1750. Now, whether the electricity be transferred through a dense or a rarefied atmosphere is of little importance, so that the intensity of the electricity be proportional to the resistance of the opposing medium. It seems probable that it is the existence of an electrified atmosphere that produced the deflection of the needle.

As early as the year 1746, it was observed that electricity disturbs the position of the magnet needle. "Having lately had occasion," says an anonymous writer in the Philosophical Transactions, "to compare together two compasses of a different maker, I happened to wipe off some dust which lay upon the glass of one, and thereby put the needle, which was before at rest, into a violent disorderly motion, partly horizontal, and partly vertical or dipping. After several repetitions of the same thing, I found that the glass by so slight a touch, was at that time excited to electricity, so far as to disturb the needle extremely." This result, however, may, perhaps, be traced to the ordinary principle of attraction and repulsion, and does not depend upon any peculiar relation of the magnetic and electrical causes.

Effects on Substances containing Iron.

When accumulated electricity is discharged through substances containing iron, and not possessing the magnetic property, it induces a magnetic state. Franklin observed, that by transmitting the charge of four large jars through a common sewing needle, it became possessed of the magnetic properties; and when made to float on water upon a piece of cork, arranged itself in the magnetic meridian, that end of the needle at which the positive electricity entered being always the north pole, except when the needle was arranged north and south at the time of the discharge, and then the end which pointed to the north always became the north pole in whatever direction the electricity passed through the needle. Beccaria and Van Marum repeated these experiments; but after an elaborate series of observations they failed to ascertain any important new fact.

Experiments upon the magnetic property of electricity on substances containing iron will be best made by placing the substances to be experimented on, in a helix formed of a metallic wire, the coils being separated from each other, either by distance or by some non-conducting substance.

It is well known that atmospheric electricity, as well as that accumulated by the electric machine, will, when discharged through substances containing iron, induce in them magnetic properties. Franklin discovered that substances containing iron were rendered magnetic by electricity; and Beccaria found that this effect was produced, how small soever may be the amount of iron contained. Even common bricks become possessed of polarity when struck by lightning. The iron bolts used in the construction of vessels, and the iron ties in walls will, if examined, frequently be found to possess this remarkable property.

From these remarks it will appear, that the passage of electricity through substances containing iron has a most important influence upon the magnetic principle. It induces polarity in substances that were before destitute of this characteristic; it destroys or disturbs it in substances that did possess it; and, under some circumstances, the needle loses in part its accurate direction, and is made to deviate more or less from its accustomed position. Now, it would appear that there is some intimate, though untraced, connexion between the electric and the magnetic principle, though we shall not at present enter upon the investigation of this interesting subject. The magnetic effects of electricity are most powerfully developed when voltaic electricity is employed; and so numerous are the results that have been obtained, that it has been considered necessary to class them together under the name of Electro Magnetism.

LUMINOUS EFFECTS.

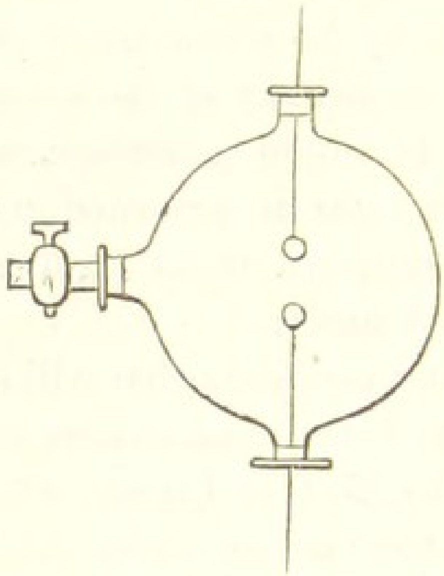
We have already had occasion to refer to the production of light as a frequent attendant upon electrical discharges, and we shall now enter more fully into the examination of the phenomenon. The early experimenters imagined that the luminous appearance was the electricity itself made visible, which they supposed to arise from a particular degree of accumulation. But it has been already stated that common air becomes luminous by violent compression; and that M. Biot, a French philosopher, was led, from a knowledge of this fact, to suppose that electric light was occasioned by the condensation of the air from the passage of electricity through it.

Under ordinary atmospheric pressure, the electric spark is white; but its colour will be changed with the character of the substance it enters, and the distances of the bodies from each other. Generally speaking, in the experiments we make, electricity passes from and enters into metallic substances, and, under these circumstances, white light is produced. But if the finger be presented to the electrified substance, the spark is violet; if water or a green plant be presented, the spark is red. Even when the same conductors are used, the colour of the electric spark may be changed by increasing or diminishing the distance between the electrified and the conducting substance, for by so doing the resistance offered by the atmospheric medium is changed. Thus, if a metal ball be brought near to a conductor provided with a sharp point, and kept in constant excitement by a machine, the colour of the light will change with the distance between the two conductors, that is, with the striking distance. When the sphere is near to the point, the transmission of the electricity will take place in a continued succession of white sparks. As the striking distance increases the whiteness decreases, and a reddish tinge will be observed. The explosions will then cease to strike the same point of the sphere, but will be directed to different points over a certain extent of surface. At a still greater distance a cone of feeble violet light will be produced, having its tip at a point of the substance from which the electricity issues, and extending its base over the nearest half of the sphere. These are changes produced by the alteration of distance between two substances, the density of the atmosphere remaining the same. It would, therefore, appear that the colour of electric light is governed by the nature of the substances employed in its production, and their distance from each other.

There is another condition that will affect the colour of electrical light. If the experiments we have described had been made by M. Gay Lussac, when he ascended to the height of 4000 metres above the level of the sea in his balloon, the same results would not have been obtained; or if we were to repeat them in a receiver partly exhausted of its air. This arises from an alteration in the density of the atmosphere, and it is evident that a rarefied atmosphere cannot present the same resistance as one that is more dense.

Take a glass globe (fig. 34) having three open necks. Let two of them be fitted with brass caps having sliding metallic rods passing through them air tight, so that the knobs, which are placed on the interior ends, may be fixed at any distance from each other. The other opening must be furnished with a stopcock and screw, so that it may be attached to the air-pump, and the air it contains be rarefied to any degree that may be required. When an experiment is to be made, one wire must be attached to the prime conductor of the machine, and the other communicate with the ground. If the machine be

Fig. 34.



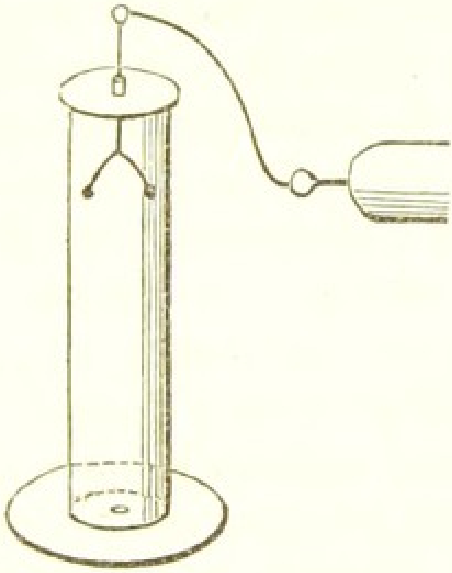
Instrument to show the influence of a change in the atmospheric density upon the colour of electric light.

then put into action, a series of sparks will be observed in the interval between the two balls. If the enclosed air be of the usual atmospheric density, the light will have a white appearance; but if the density be diminished, the whiteness will diminish also, and a violet tinge will be observed; for, as the resistance of the atmosphere is less, the electricity will pass from one ball to the other before it has attained the same degree of intensity.

The following experiment is worthy of notice in this place, as tending to illustrate this branch of our subject.

Experiment. If a glass tube (fig. 35), such as is employed in the guinea and feather experiment, be connected with the prime conductor of an electric

Fig. 35.



Experiment to show the beautiful light produced by the passage of electricity from points through a rarefied atmosphere.

machine, by a copper wire, the wire entering the tube to the distance of three or four inches, electricity may be passed through it without producing any luminous effect. But place the tube upon the plate of an air-pump, and rarefy the enclosed air ; then pass a current of electricity through the wire as before, and in a very short time a luminous appearance will be observed, which will be more and more diffused over the surface of the glass as the exhaustion proceeds.

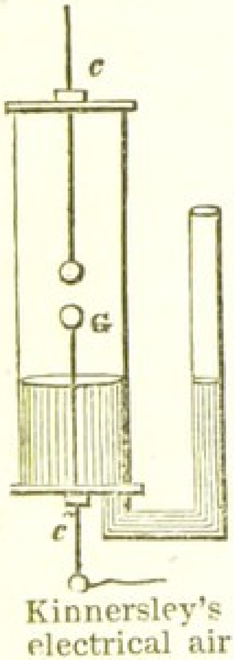
From this experiment we deduce that the density of the air prevented, in the first instance, the passage of the electric agent ; but when that resisting force had been removed, it escaped from the wire, while, at the same time, a sufficient pressure was exerted to produce light. Could a perfect vacuum be obtained, and electricity be made to pass through it, no luminous effect would be observed, upon the principles of the theory we have mentioned; but it does not appear probable that either of these conditions can be accomplished.

It would also follow, from the statements that have been made, that the electricity of the greatest intensity should produce the whitest spark, the density of the atmosphere being the same. Thus, in the apparatus, figure 34, the spark between the two balls produced by the discharge of a jar charged with great intensity, should be whiter than that produced by the same amount of electricity distributed over a larger surface. This will be found by experiment to be the result.

But luminous effects are also produced by the passage of electricity through other substances beside air. Many, if not all, the other elastic fluids would equally exhibit the results we have described, and some of the non-elastic. If a number of peeled oranges or eggs, piled one upon another, be placed in the electric circuit, and a charge be transmitted through them, they will become luminous. A spark would also be produced by the passage of electricity between the balls of the receiver, figure 34, even if it were filled with water. Some have attributed the luminous appearance in these two experiments to the compression of the particles of the water; and, as it has been proved that water is capable of compression, no very strong arguments could be used against the supposition; but, at the same time, we are inclined to believe, that M. Biot's theory is quite sufficient to account for the phenomenon, if received as an explanation of an instance of luminous appearances by electricity; for all fluids enclose a portion of atmospheric air. There are, however, some who doubt whether the luminous appearance may not be more fairly attributed to some peculiar property in the electricity itself; and, as a farther argument in favour of M. Biot's theory, we may allude to an experiment that at least proves that air is compressed by the passage of electricity through it.

Figure 36 is a representation of Kinnersley's air thermometer. G is a small glass cylinder, the ends of which are fitted with air-tight metallic caps *c c*, through which two wires are made to slide. These wires are terminated by brass balls, so that a strong spark may be produced by the passage of electricity from the one to the other. To the bottom of the cylinder is attached a small tube, through which is poured sufficient mercury to cover the bottom of the cylinder to some depth. The mercury acts as a valve, and any expansion of the confined air will of course force the mercury up the tube. Having formed a communication between one wire of the cylinder and the earth by means of a chain, connect the other with the prime conductor of the machine in action, and a series of sparks will be observed to pass between the two balls, and after each spark the mercury in the tube will be observed to rise. This effect is occasioned by

Fig. 36.



Kinnersley's electrical air thermometer.

the pressure of the air upon the mercury, which pressure could not be produced without its compression. By this instrument, therefore, we may not only prove that air is compressed by the passage of electricity from one body to another, but the amount of compression may be measured. The advocates of M. Biot's theory, having thus proved the compression of air, state, that it is sufficient to account for the production of light; but it may be asked, what proof can they give that the amount of pressure thus effected is sufficient to produce light, for there is certainly a degree of compression which the air might suffer without producing light. The arguments in favour of the theory are not, we must confess, quite conclusive.

Dr. Fusinieri has more recently proposed another theory. He supposes the spark to consist of fused particles of the substance from which the electricity issues, and that it is, in fact, a flame. The explanation given of flame in the "ALPHABET OF CHEMISTRY[1]," will render it unnecessary for us to explain this theory in detail. It is sufficient to say, that this theory is supported by strong, if not conclusive experiments.

The luminous effects produced by the passage of electricity from one substance to another, may, perhaps, be further illustrated by the mention of a few of the most important experiments which are made by lecturers when treating of this subject.

Experiment 1.—If a piece of tin-foil be pasted upon a plate of glass, it may be cut into the form of any

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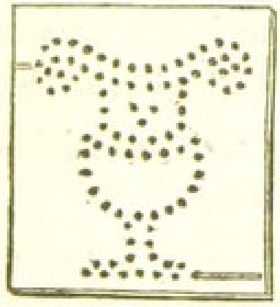
(1) ALPHABET OF CHEMISTRY, second edit., p. 87.

device that may be required. Let it, for instance, be cut into the form of a vase. Now we have seen that no luminous appearance is presented by the passage of electricity through a perfect conductor, but if an imperfect conductor intervene between two perfect conductors, light is produced. If, therefore, we pass electricity through this tin-foil vase, no light will be produced except at the point where the electricity enters, and that where it makes its exit. But if the vase consist of a series of pieces of tin-foil (fig. 37), light will appear in every place where there is an obstacle to the passage of the electricity, and, on account of the velocity with which it passes from one body to another, the entire device will appear to be illuminated at the same moment, a continuous line of light being apparently produced. By properly arranging the tinfoil, any figure may be represented, and the entire art of constructing these luminous representations consists in arranging the tin-foils at proper distances, and in giving the electricity a continuous circuit. Short words, such as "Light," and "Science," are frequently adopted, and are very suitable for these glasses.

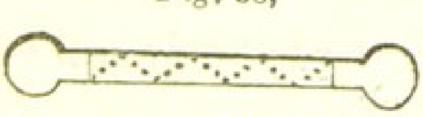
Fig. 37:



To show electrical light.

Experiment 2.—A modification of the last experiment is represented in figure 38. It is a glass tube, round which is pasted a number of small circular pieces of tin-foil in a spiral form. If this tube be held in the hand, and

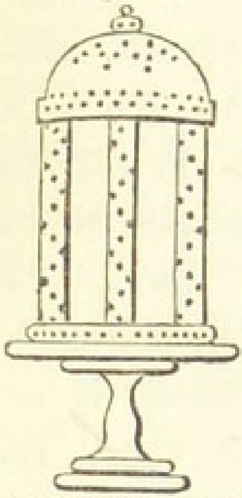
Fig. 38,



The electrical light tube.

presented to the conductor of an electrical machine, the electric fluid will be transferred through it, and a spiral line of light will be produced. A number of these are sometimes combined (fig. 39), and a very beautiful effect is produced by the simultaneous illumination of the whole arrangement.

Fig, 39,



An instrument to exhibit electrical light.

Experiment 3.—The same effect may be produced by passing a charge of electricity through a piece of chain. Suspend a long piece of chain in the form of a wreath, and connecting one end with the outer coating of a Leyden jar, let the other be attached to the discharging rod. As soon as the rod touches the knob of the jar, a circuit is formed, and the electricity is conducted to the exterior coating of the jar by the chain, which is illuminated throughout the whole of its length.

Experiment 4.—Place a short chain upon a table, one end of it being in contact with the exterior coating of a charged jar, and within a quarter of an inch of the other end fix another chain, and upon these two ends place a glass of water. When a communication is formed between the exterior end of the second chain and the knob of the jar, a discharge takes place through the chains, and the glass will be brilliantly illuminated.

All these experiments may be easily performed by the student; and we would again recommend him to satisfy himself of their accuracy; for not only will he thus become better acquainted with the appearances we have described than he can do by reading, but he will also have an opportunity of examining the circumstances under which luminous appearances are produced, and thus provide a foundation for thought, and for independent opinion.

Before we leave this subject we may briefly refer to an interesting series of experiments made by Mr. Skrimshire, which seem to us to be connected with the facts to which we have been alluding. This gentleman found that when a discharge was made over or above some substances, they acquired a phosphorescent appearance, which continued some time after the experiment had been made. All substances containing lime are, under these circumstances, more or less phosphorescent. Common chalk was rendered extremely phosphorescent by passing a shock at some distance above it, but when upon the surface, a vivid zig-zag line of light was left, which continued for some minutes. All bones, marbles, and limestones, became luminous by the absorption of electricity; and upon some of them the phosphorescence was very bright, and continued for a considerable time. There are other classes of minerals which exhibit the same appearance, but those that are of a calcareous nature are most suitable for experiment, and generally produce the most vivid phosphorescence.

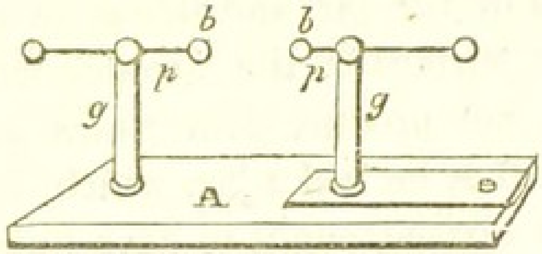
We do not pretend to explain this curious class of phenomena, for it is not only impossible to investigate the peculiar influence of electricity upon these substances, but we have no facts upon which to form even an opinion of the cause from which the appearance arises. Nor must the student imagine this a singular instance; for as he advances in his knowledge of science he will find that he cannot explain one half of the things that he sees, and can never trace an appearance to its ultimate source. He may know that a substance will be melted by heat, but the agent which he calls heat cannot be made visible nor tangible in a separate form. He may know that an eclipse is produced by the apparent passage of one body over the place of another, but no philosopher can answer the question, What is motion? Thus even the wisest men are taught their ignorance, and learn, what is generally only acquired by experience, to use that difficult phrase, "I do not know."

HEATING EFFECTS.

When electricity is transmitted through metallic wires such a degree of heat is evolved as always to raise their temperature, and frequently to produce their ignition. By passing a strong charge through a very fine iron wire, it will be raised to a red heat, and, if the charge be sufficiently strong, it will be melted. It was once customary to employ very large batteries for these experiments, but if a very fine wire be employed, the charge from a large jar will be sufficient to fuse it. The flatted steel wire known by the name of watch pendulum wire is the best that can be used.

Figure 40 represents the best form of apparatus that can be employed for experiments on the fusion of wires. A, is a stand, having a slide which can be

Fig. 40.



moved outwards, so as to increase the distance between the balls, *b b*, at pleasure; *g g* are glass rods, one being fixed in the stand, the other in the slide. The balls are made solid, and a small hole is drilled through them, through which the wire is passed, and fixed by means of a metallic plug, *p*. If one of the balls be connected, by a wire, with the exterior coating of a charged jar, and the other with the knob of the jar, the fine wire is made a part of the electric circuit, and will be fused by the passage of the electricity, if the charge be sufficiently strong.

A great number of experiments were made by Brooke, Cuthbertson, and Van Marum, upon the ignition and fusion of metallic wires. Brooke and Cuthbertson were led by their experiments to the conclusion that two jars, charged to any given degree, would melt four times the length of wire that is fused by one jar, or, in technical terms, that the action of electricity increases in the ratio of the square of the increased power. Van Marum, however, states that the length of wire that may be fused is directly in proportion to the extent of coated surface; but Singer, who was one of the best practical experimenters of his day, agrees to the law proposed by Cuthbertson. We must, however, remind the beginner of a fact already noticed, that the power of accumulation depends upon the thickness of the jar, and therefore we may double the extent of surface by the introduction of a second jar, and yet not produce four times the effect. Mr. Singer states that he had a jar, which, from the extent of its coated surface, ought to have fused three feet of wire, and could only produce the effect upon eighteen inches.

It is curious to watch the change of effect, as the power of the charge is increased. If steel or iron wire be used, a gentle charge will cause it assume a blue colour; if the charge be increased, it becomes red-hot, then is dispersed in a shower of red-hot globules; and if a still stronger degree of accumulation be employed, an instantaneous bright flash will be observed, followed by an appearance which resembles vapour, but which is in fact a fine powder, consisting of the metal united with a portion of oxygen derived from the atmosphere.

With a large battery a great length of wire may be fused. Van Marum fused 50 feet of iron wire, the 1-140th of an inch in diameter, with a battery consisting of 225 square feet of coated surface; and after the discharge had been made, there was a sufficient residue of fluid in the battery to fuse two feet of the same wire.

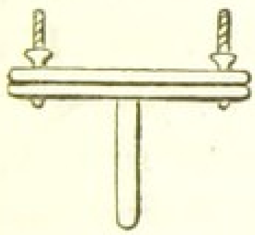
We have many instances on record of the heating effect of atmospheric electricity. In 1708 there was a violent storm in Essex, and four persons, who were going from Harwich to Ipswich in a boat, were killed by a stroke of lightning, the chain and watch in the pocket of one being fused. On another occasion, lightning fell upon a box of knives, and melted several of them. But the instance most appropriate for our present purpose is detailed in an account of the effects of a storm of thunder and lightning at Rickmansworth, in 1759. This paper contains an interesting description of the destructive effects produced by this storm, and among others, it states that the bell-wires were in many places entirely fused, the small metallic globules being distributed over the room, and producing the appearance of a shower of fire.

It is probable that the evolution of heat by the passage of electricity through metallic wires may be produced by the sudden transit of the agent, and particularly by its great condensation when made to pass through a very small channel. This, however, is not of itself sufficient to account for the effect, although we are well aware of the influence of violent impact in raising the temperature of a body. Cavallo appropriately remarks, "that the degree of fusibility of different metallic substances, when exposed to the action of electric shocks, is by no means the same as takes place in chemical furnaces, which shows that the electric agent is not the same thing as the element of fire, the effects in general seeming to be proportionate to the degree of resistance which it meets with in its passage; but with respect to metals, the degree of fusibility which they show in this way, seems to be in the compound proportion of that resistance which each particular metal offers to the passage of the electric agent, and of its natural degree of fusibility, when exposed to a common fire."

It might be expected that when a charge is passed through a metallic substance sufficient to heat, but not to fuse it, that it would suffer some degree of expansion in consequence. It was observed by Dr. Priestley, that a chain through which a charge had been passed had suffered a lateral expansion,—that is to say, a diminution in its length. A chain twenty-eight inches long lost a quarter of an inch of its length by conducting a charge from sixty-four square feet of coated surface. Mr. Nairne took a jar, having the same amount of surface, and after passing a number of shocks through a piece of hard drawn iron wire ten inches long, he found that it had suffered a contraction lengthways of one inch and one-tenth. The lateral expansion,—that is, the increase of thickness, is in all these cases proportional to the longitudinal contraction, and no diminution of weight could be discovered. But if a weight sufficient to produce a considerable tension be suspended from the chain or wire through which the shock is passed, it will increase in length. This fact plainly shows that the alteration of length arises from an increase of heat, which gives to the particles of the body a great freedom of motion among each other; and as the force is in the direction of the length, in the last case the chain is lengthened; and as in the others there is nothing to resist the expansion, it increases in thickness.

Franklin observed that metal plates often suffered fusion by the transmission of electrical discharges through them. To produce this effect he enclosed the metal, a gold leaf, for instance, between two plates of glass, firmly bound together. Upon placing this arrangement in the electric circuit, and discharging the electricity of a large jar or battery through the metal, it frequently undergoes oxidation, and combines with the surface of the glass, which is, however, frequently broken. Another arrangement, therefore, (fig. 41) has been employed to perform this experiment. It consists of two ivory plates, between which is placed a paper pattern of some device, a gold leaf and a piece of satin in the order we have mentioned, the whole of which is enclosed in a wooden press. A strong charge is then passed over the under surface of the paper pattern which lies at the bottom of the series, and in all those places where it has been cut away to form the device, the gold leaf which lies upon it conducts the electricity, and being fused, stains the satin which is above it, and forms a representation of the figure upon the surface of the satin. A bird or a portrait may be used with success.

Fig. 41.



Apparatus to show the oxidation of metal by accumulated electricity.

The expansion of fluids, by the passage of electricity through them, is probably to be attributed to the compound influence of mechanical compression, and the increase of temperature. If a capillary tube, such as is used for thermometers, be filled with mercury, and a powerful charge be transmitted through it, the expansion will be sufficient to break the glass, although the mercury is an excellent conductor. This effect probably arises from a variety of causes. The mercury itself may be expanded by the compression in one direction of its particles, as well as by its increase of temperature; and this same duplicate influence is exerted upon the air, which it, in common with other fluids, contains. A great pressure, therefore, is exerted upon the interior surface of the tube, which almost invariably occasions its fracture.

When the fluid has an inferior conducting power, the expansion is much greater than in other cases. If a glass tube be filled with water, and corks be placed at the ends, and wires be passed through them so as to meet within half an inch, the tube will be broken and the water dispersed by the passage of a moderate shock. Mr. Morgan broke green-glass bottles, and we have fractured glass tubes nearly three quarters of an inch thick in the same way. Beccaria placed a drop of water between two wires in the centre of an almost solid glass globe, two inches in diameter, and on passing a charge through the water the globe was broken into pieces.

We do not pretend to say that in all the instances we have just mentioned, the effect is to be entirely traced to the evolution of heat arising from the passage of the electric agent through the substance; but we believe that it may, in a great measure, be attributed to this circumstance. Under particular circumstances, a liquid may even be made to assume the form of vapour, and the expansion which it must then suffer is well known. We do not therefore think it very improbable that the effects we have mentioned as resulting from the passage of electricity through liquids, may be traced to the increase of their temperature.

The class of facts that have just been examined, can no more be explained, than those mentioned in the previous section, that is to say, we have equal difficulty in ascertaining the origin of the heat that is developed, as of the light. It is true that the sudden and violent motion of the electric agent may, upon the theory of impact, in some measure account for the phenomenon, as it did in the former instance. But as we are almost entirely ignorant of the connexion between the material causes of light and heat, so we are in the present instance incapable of tracing the phenomena themselves to any general principle, much less of proving their origin from any peculiar action or condition of electricity.

By the spark from a Leyden jar, gases, spirits of wine, ether, and many other inflammable substances, may be inflamed. Place a person upon an insulating stool, and let him hold in one hand a metal ladle containing spirits of wine, and with the other let him hold a chain connected with the prime conductor of a machine in action. If any second person bring his hand near to the electrified spirit, a spark will be produced by the passage of the electricity to his own body, and the spirit will be inflamed.

The same result does not follow the passage of an electric charge over gunpowder. If gunpowder be placed on the table of an universal discharger between the wires, and the charge of a jar containing a square foot of coated surface be transmitted over it, it will be invariably dispersed without inflammation. But if we take a glass tube, about six or eight inches long, and about a quarter of an inch in diameter, and, filling it with water, insert corks at each end, with wires through them so as to form a conducting communication with the water, and, placing this water tube in any part of the circuit, make the discharge as before, the gunpowder will be inflamed. This singular result we do not profess to explain. We are indebted to Mr. Woodward, whose name will long be honourably associated with the science of electricity, for this interesting discovery.

CHEMICAL EFFECTS.

Ordinary electricity, or that derived from friction, of which kind we have been speaking, has been long known to produce certain chemical effects; but its influence in the decomposition of compound substances, and the formation of new ones, is by no means so great as that of the voltaic electricity. Great care is necessary in order to distinguish the purely chemical effects from those which are produced by the mere elevation of temperature resulting from the passage of the electric fluid. The oxidation of wires or metallic leaves cannot be classed among the chemical effects, for the intense heat produced by the passage of the fluids through these bodies is quite sufficient to enable the metal to combine with the oxygen of the atmosphere, and to pass into the state of an oxide. We have therefore treated of this class of phenomena under the head of heating effects.

Dr. Priestley appears to have been the first who experimented upon the chemical effects of ordinary electricity, if we except the experiment of Warltire, who had fired atmospheric air and hydrogen gas by its means. His first experiment was the production of nitric acid by the discharge of electric sparks through water containing atmospheric air. This was done by passing a current of sparks through a small quantity of water coloured blue by litmus, contained in a glass tube. After the sparks had passed for two or three minutes, the liquid acquired a reddish tinge, particularly at that part where the sparks entered, while the air confined in the tube suffered evident diminution. This effect arose from the formation of nitric acid by the combination of the oxygen and nitrogen of the enclosed air. Liquid nitric acid, which is a combination of nitric acid gas and water, seems to have been first produced by Raymond Lully, the celebrated alchemist. The direct formation of this substance was performed by Priestley, in the experiment we have just explained; but we are indebted to Mr. Cavendish for the investigation of the effect, and the discovery of its character. For a detail of the very beautiful experiments he made, we refer the reader to the Philosophical Transactions for 1784.

By passing a current of electric sparks through olive oil, turpentine, and ether, Dr. Priestley found that an inflammable gas was always evolved; and by operating in the same manner upon carburetted hydrogen, charcoal in a pulverulent form was deposited upon the inside of the tube;—this experiment, however, succeeded best when two or three shocks were discharged through the gas instead of a current of sparks.

Several other experiments were made by Priestley, proving the chemical action of ordinary electricity, but they need not be enumerated here, as their chief importance is found in the proof they afford of the chemical influence of the electric agent.

The next series of experiments in the order of time, were those of Van Marum, who, with the great Teylerian machine at Haerlem, examined the effect produced by the passage of the electric spark through the different gases; but no very remarkable results were obtained from his long and tedious series of observations.

In the year 1789, Messrs. Paets, Van Troostwyck, and Dieman, associated with Mr. Cuthbertson, entered into the investigation of the effects of electricity upon different substances, and succeeded in decomposing water by electric shocks. The description of the apparatus by which they accomplished this effect, may not be altogether uninteresting.

The tube to contain the water was about 1-8th of an inch in diameter, and a foot long. One end of the tube was hermetically sealed with a gold wire fixed in it, which projected within the tube about an inch and a half. The other end was open, and at the time of the experiment was immersed in a small glass vessel of distilled water. Another wire passed through this open end up the tube to within about 5-8ths of an inch from the other wire. Between the points of the wire, according to this arrangement, there was a small quantity of water, and through this the charges were to pass. To make the discharge, the extremity of one of the wires was connected with the outside coating of a Leyden jar, whose knob communicated with the prime conductor of a machine. The other wire was placed against an insulated ball at a striking distance from the knob of the jar. By this arrangement, the jar, which had about one square foot of coated surface, was made to discharge itself twenty-five times in fifteen revolutions of a powerful double plate machine, decomposition was speedily accomplished, and the upper part of the tube was filled with the gases which compose water, and these were made to take the liquid form again as soon as a discharge was passed through them.

This was the first instance of the analysis of water by common or ordinary electricity, and no further information on the subject was obtained until the year 1801, when Dr. Wollaston published, in the Philosophical Transactions, a description of the method which he had employed to produce the same effect by sparks, instead of shocks. The following is his own account of the process by which he effected the object.

"It has been thought necessary for the decomposition of water, to employ powerful machines and large Leyden jars; but when I considered that the decomposition must depend upon duly proportioning the strength of the charge of electricity to the quantity of water, and that the quantity exposed to its action at the surface of communication depends on the extent of that surface, I hoped that, by reducing the surface of communication, the decomposition of water might be effected by smaller machines, and with a less powerful excitation, than have hitherto been used for that purpose.

"Having procured a small wire of fine gold, and given it as fine a point as I could, I inserted it into a capillary glass tube; and after heating the tube so as to make it adhere to the point and cover it in every part, I gradually ground it down till, with a pocket lens, I could discern that the point of gold was exposed.

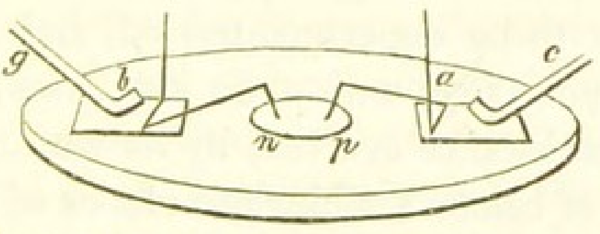
"The success of this method exceeded my expectations. I coated several wires in the same manner, and found, that when sparks from the conductors before mentioned were made to pass through water, by means of a point so guarded, a spark passing to the distance of 1-8th of an inch would decompose water when the point exposed did not exceed 1-700th of an inch in diameter. With another point, which I estimated at 1-15,000th, a succession of sparks 1-20th of an inch in length, afforded a current of small bubbles of air."

By these and other experiments, Dr. Wollaston shows the resemblance between the chemical effects of ordinary and voltaic electricity. It must, however, be admitted, that the decomposition of water by the electric machine, in both these instances, has nothing more than a resemblance to the decompositions of the voltaic battery, and has consequently been objected to by all those who deny the identity of ordinary and voltaic electricity. "The decomposition of water by ordinary electricity," says Dr. Ritchie, "seems to have been effected by the mechanical agency of the electric fluid. The fine electric dart shooting out from the invisible gold points may have actually cleaved a molecule of water which happened to be favourably situated, and thus its oxygen and hydrogen were disengaged at a point where the mechanical cleavage took place."

Dr. Faraday, however, has succeeded in decomposing water in a manner perfectly analogous to that accomplished by voltaic electricity. Previous to his experimental investigation of the subject, oxygen and hydrogen were evolved from both poles, whereas in voltaic decomposition oxygen is evolved from one pole, and hydrogen from the other, but Dr. Faraday has obtained the same result by the agency of ordinary electricity.

We cannot leave this department of our subject without extracting the description which Dr. Faraday has given of the apparatus which he has employed for chemical decomposition. "Upon a glass plate (fig. 42)

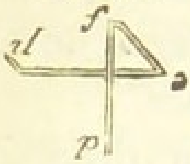
Fig. 42.



Dr. Faraday's apparatus for chemical decomposition by common electricity.

placed over but raised above a piece of white paper, so that shadows may not interfere, put two pieces of tinfoil *a*, *b*; connect one of these by an insulated wire, *c*, with the machine, and the other, *g*, with the discharging train, or the negative conductor; provide two pieces of fine platina wire, bent as in fig. 43, so that the part *d f* shall be nearly upright, while the whole is resting on the three bearing points, *p*, *e*, *f*; place these as in fig. 42, the points *p n* then become the decomposing poles. In this way surfaces of contact as minute as possible can be obtained at pleasure, and the connexion can be broken or renewed in a moment, and the substance acted upon with the utmost facility.

Fig. 43.



"A coarse line was made on the glass with solution of sulphate of copper, and the terminations *p* and *n* put into it; the foil *a* was connected with the positive conductor of the machine by wire and wet string, so that no sparks passed: twenty turns of the machine caused the precipitation of so much copper on the end *p*, that it looked like copper wire; no apparent change took place at *n*

"A still further improvement in this form of apparatus consists in wetting a piece of filtering paper in the solution to be experimented on, and placing that under the points *p* and *n* on the glass; the paper retains the substance evolved, by its whiteness renders any change of colour visible, and allows of the point of contact between it and the decomposing wires being contracted to the utmost degree.

"A piece of litmus paper moistened in solution of common salt was quickly reddened at *p*. A similar piece, moistened in muriatic acid, was very soon bleached at *p*. No effects of a similar kind took place at *n*.

"Care must be taken not to allow a spark to pass over to the litmus or turmeric paper, or it will be reddened, which is due to the formation of nitric acid by the combination of the oxygen and nitrogen of the air, and is, indeed, only a repetition of Cavendish's beautiful experiment."

Under the head chemical effects, we may perhaps speak of the increased rapidity with which putrefaction proceeds in all animal or vegetable bodies which have been killed by electricity. It is also well known that a storm frequently gives a putrid smell to meat; and grain under fermentation, as in the process of brewing, suffers a very sudden change, and is often rendered useless. M. Achard, of Berlin, recently investigated this subject with a view to determine the influence of electricity, which is always present in the atmosphere in stormy weather, in producing these effects. By his experiments, he was led to the conclusion that whenever flesh is electrified, or animals killed by electricity, the progress of corruption is greatly accelerated, and that the putrefaction of flesh after a storm must be ascribed solely to the more abundant accumulation of the electric matter at that time.

In the experiments of M. Achard, we have also a decided proof that fermentation is invariably accelerated by electricity. The precise cause of this or the foregoing effect it is not easy to determine, but there is a great probability that it is by a chemical action, and on this account we have mentioned them in this place.

These remarks have, we think, described some of the most important prominent facts relating to the chemical effects of common electricity; but they are much less powerful and general than those produced by the voltaic battery. There is also a considerable difficulty in determining whether the effects which are sometimes observed, are to be traced to the influence of heat, or a purely chemical agency.

This branch of electricity, like many others, is still in its infancy, and a wide field of observation is before the industrious student. The attention of experimenters has for many years past been fixed upon other branches of electrical science, and they have as yet scarcely recovered from the effects of the wonderful discoveries that have been, and are still being made. On this account, common electricity has received much less attention than it deserved, and it has not advanced with the same degree of rapidity as its sister sciences. But the interest which is now taken in determining the analogy between the electricities derived from different sources, will, in all probability, lead to a more accurate and minute investigation of the effects of ordinary electricity, and especially of those which appear to depend upon chemical action.

PHYSIOLOGICAL EFFECTS.

WHEN an electric spark is received upon any part of the body, it produces a sharp tingling sensation, which must be well known to every one who has been accustomed to use the electric machine. When we discharge a Leyden jar through any part of our body, a sudden muscular contraction is felt, and we are said to receive a shock. The violence of the shock is proportioned to the size of the jar, or rather to the number of square feet of its coated surface. It is quite ridiculous to read the exaggerated descriptions which the early experimenters have given of the effect of the electric shock upon them, arising partly from the novelty of the sensation, and in part from their own timidity. Winkler states that when he first took the electric shock, it threw his body into such violent convulsions, and so inflamed his blood, that but for the timely aid of febrifuge remedies, he should certainly have had an attack of fever; and at another time it produced a copious bleeding of the nose; and the same effect was experienced by his lady, who was rendered so weak by the exhaustion which attended it, as to be unable to walk for some time. Muschenbroek states that he received so violent a concussion by receiving a shock, that he lost his breath, and felt its effects for two days after, nor would he, he says, take another for the whole kingdom of France. When we see children receiving the electric shock, time after time, for amusement, it is ludicrous to find philosophers thus speaking of what is now considered a pastime.

It is not easy to explain the cause of the singular effect which follows the discharge of accumulated electricity through the human frame. The involuntary muscular action may be produced by the concussion of a material agent passing through the body, by an influence on the nervous system, or by the sudden disturbance of its electric equilibrium. But we do not stop to attempt an explanation of the cause of the effects, our object is to describe the effects themselves.

It must have been observed by every one who has taken an electric shock, that the dull pain which is left after the discharge is chiefly felt in the joints. This is probably to be traced to the resistance which the electric agent experiences in passing from the surface of one bone to the other in those parts. If the charge be directed through the muscles, they are put into a state of convulsive motion, and this is even produced when the nerves are incapable of conveying sensation, as in cases of paralysis. Mr. Morgan states that if a discharge from two square feet of coated surface be made through the diaphragm, a loud shout is produced by the sudden contraction of the lungs; but if a powerful charge be passed through this muscle, involuntary crying is produced: whereas with a smaller a violent fit of laughter is indulged, even by the gravest persons.

An electric shock of the same intensity has a decidedly different effect upon different individuals, persons of great nervous irritability being more violently affected than others. This is easily accounted for, by the fact that electricity excites the nervous system especially. It was observed that a strong electric shock, passed through the head of a pigeon, caused it to lose its sight, which can only be accounted for by supposing the nerves of the eye to be destroyed by its passage, and the same effect is produced upon all animals. Mr. Singer states that a strong charge, passed through his own head, gave him the sensation of a violent blow, and was followed by a momentary loss of memory and of vision. When a person receives a moderate charge through the spine, he loses all his muscular power, probably arising from the sudden exhaustion of the energy of the nervous system, and either drops on his knees or falls prostrate on the ground. If the charge be sufficiently powerful, it will produce instant death.

For the information we have on the influence of accumulated electricity in destroying life, we are chiefly indebted to Dr. Van Marum. He took, for the purpose of experiment, eels, which are known to be most tenacious of life, and found that a charge passed through the whole length of the body instantaneously destroyed it, without leaving the slightest sign of irritability, which they evince so strongly under ordinary circumstances. When the shock was only passed through the head, that alone lost its irritability, and when through the body, the head being out of the circuit, the body was paralysed, the head retaining its irritability. The same effect was produced upon rabbits, and other warm-blooded animals. It is also well known that lightning not unfrequently kills animals, and even men, by its passage through them.

Electricity has also been employed as a medical agent, and it is strange that an inquiry, which was commenced by the belief and publication of error, should have led to such eminently successful results. Johannes Francisco Pivati was the first who wrote upon this subject, and the whole of his experiments and results have been proved to deserve no better name than deceptions. The principle upon which all his operations were founded was, that by the passage of electricity through drugs, their virtues were extracted, and could be made to act upon the animal system by conducting the electric fluid through it. This writer states, as one of his experiments, that he enclosed a quantity of balsam of Peru in a glass cylinder, and with this cylinder electrified a patient who had a pain in his side. So effectually, we are told, was the virtue of the balsam communicated, that the patient not only returned home and fell asleep under violent perspiration, but his clothes and person were impregnated with the effluvia of the balsam.

But the most singular cure was one which Pivati professed to have made on the person of Signor Donadoni, bishop of Sebenico, who was seventy-five years old, and so greatly afflicted with the gout, that the joints of his fingers were fixed, and his knees unable to bend. Pivati adopted the same plan as he had before tried with success, and in two minutes after the application, he says, "his lordship opened and shut his hand, gave a hearty squeeze to one of his attendants, got up, walked, smote his hands together, helped himself to a chair, and sat down wondering at his own strength, and hardly knowing whether it was not a dream. At length he walked out of the chamber down stairs without any assistance, and with all the alacrity of a young man."

The French philosophers soon after made the experiment, and failed, and were not more successful after they had received some properly prepared tubes from Winkler, who professed to have verified the results of Pivati. The Abbé Nollet afterwards visited Italy, to observe for himself these wonderful results, but he returned with the conviction that the virtues of plants are not transmitted by electricity, but that paralysis and some other diseases are frequently relieved by electricity itself.

When we consider the success that has attended the application of medical electricity, it would appear strange that it is so little employed, did we not know the effect which imposture always has in retarding the reception of any peculiar remedy by the practitioner or the patient. To this cause we may attribute the slow advance of the science of medical electricity. It is, however, now very generally employed in our hospitals, and is often recommended by some of our most eminent physicians, and we may hope that it will soon rise to an equality with other branches of the medical profession, and be governed by principles similar to those which regulate the practice of medicine. At the present time, it requires, more than any other science, accumulated observation and experiment, which can only be supplied by those who are engaged in administering electricity. It is little less than a disgrace to the profession, that the practitioner should, in the present day, be so undecided as to the influence of electricity upon the disorganised human system, and be so unable to give a reason for or against the use of this wonderful agent in medical cases.

It would not be proper to enter upon a detail of the several diseases in which electricity may be employed with advantage. But it may not, perhaps, be improper to remark that there are two diseases which scarcely fail to give way to its influence, when properly administered,—rheumatism and ague. The usual method of applying electricity is by sparks or shocks, but it may be doubted whether the effects produced by these means are at all equal to those which result from the quiet passage of the agent through the affected part of the patient, that is, in the cases to which we have just alluded.

Effect of Electricity upon Vegetable Life.

Mr. Maimbray, of Edinburgh, was the first experimenter upon the influence of electricity upon vegetable life. From the experiments of this gentleman, it appeared that the gentle application of electricity caused two myrtle trees to put forth their leaves at a much earlier period than trees of the same species which had not been electrified.

The Abbé Nollet, Boze, the Abbé Bertholon, and other experimenters, directed their attention to the same subject, and thought that they had fully verified the observations of Maimbray. Bertholon was so sanguine as to the effects of electricity, that he proposed a system of agriculture by which it might be communicated to the whole of a garden, or of a farm.

Dr. Ingenhouz afterwards entered upon a very elaborate series of experiments, from which he deduces that electricity does not at all act as a stimulus to vegetation, and Cavallo agrees with him in opinion.

It is difficult to decide, without experiment, between the conflicting opinions of such eminent experimenters; but it does appear to us almost impossible that electricity should be devoid of influence upon vegetable life.

There is a certain analogy between the vegetable and animal economy, and we have seen the important influence of electricity upon the latter, and might hence deduce that it would produce some effect upon the former. But in addition to the argument which might be established on this ground, it may be mentioned that electricity always increases the velocity of a fluid moving in a capillary tube. Now the organisation of a vegetable is a system of these tubes, and it is almost certain that the circulation of the fluids they contain must be increased by the action of electricity. The increased velocity in the circulation of the vegetable juices must have some influence upon the vegetable itself, since its health and life is dependent on an orderly circulation.

But although feeble electricity has no very marked influence upon vegetable life, even when applied for a considerable time; yet accumulated electricity, discharged through them, has a decidedly destructive effect, and probably affects them in the same manner as it does the animal system. Van Marum passed a charge through parts of the stems of some young willows, and afterwards planted them. The parts through which the shock had been passed sent forth no shoots, while the other parts were equally as vigorous as those trees planted near them which had not been experimented on.

It is not a little difficult to explain the cause of the destructive effect of electricity upon plants. We may trace the death of the animal in most cases to the excitement of the nervous system, and in others it may be attributable to the mechanical influence of the accumulated agent. It would also appear probable that the organisation of vegetables is often disturbed by the passage of the electricity, and that the destruction of the vital energy of a plant may be traced to this cause, as well as to the mechanical effect of concussion. Cavallo states that "a very small shock sent through the stem of a balsam is sufficient to deprive it of life. A few minutes after the passage of the shock, the plant will droop, the leaves and branches become flaccid, and, in short, its vegetation is quite destroyed. A small Leyden phial, such as may contain six or eight square inches of coated surface, is sufficient for this purpose; and it may even be effected by strong sparks from the prime conductor of a large electrical machine. In this experiment neither the internal vessels, nor any other part of the plant, appeared to be injured; and, indeed, the size of the plant, and the inconsiderable strength of the shock which was used, were such as not to indicate the possibility of the vessels being burst, or of the vegetable organisation suffering any material derangement."

It is possible that the derangement may not be perceptible; but we cannot imagine what can cause the death of the plant, if the organisation be not materially deranged. No visible mark can, in some cases, be traced upon the bodies of animals killed by electricity; but there can be no doubt that the organisation was disturbed by its passage, and that the death of the animal can only be attributed to that circumstance. So, in the instance before us, the vegetable organisation may be injured in parts too delicate for detection, and we may be unable to trace any visible alteration in the structure of the plant, although some delicate but vital part may be injured or destroyed.

The physiological effects of electricity show, in the most striking manner, the importance of this agent in the animal and vegetable economy. When organised bodies become the conductors of an accumulated quantity of electricity, the destruction of all their vital energies is the inevitable consequence. If their natural electric state be disturbed, they suffer, or at least the animal system feels, the effect. To the constant variation in the electric condition of the atmosphere, we may probably trace the change of feeling which we experience by the alteration in the weather. In a wet and damp state of the air, the electricity of the body is carried away, and the system deprived of a portion of its natural quantity; when electricity is abundant, or at least when it is in motion, as in thunder-storms, we feel depressed, and weak or nervous persons are frequently greatly distressed, and to them it is often the forerunner of illness.

MECHANICAL EFFECTS.

It is possible that some of the effects already described may be traced to the mechanical influence of electricity. The increase of temperature, resulting from a discharge through an insufficient conductor, may, perhaps, be traced to mechanical concussion;

and the same cause will explain some of the results which have just been mentioned. The principal effect to be noticed now, is the expansion of bodies by the passage of electricity through them, and this will be best illustrated by the enumeration of a series of experiments.

Experiment 1. Fill a thermometer tube with mercury, and let the metal form a part of the circuit through which accumulated electricity is to pass. If it be thus made the conductor for a moderate charge, the tube will be burst by the sudden expansion of the fluid.

Experiment 2. Take a tube to which corks have been fitted, having wires passed through, and the interior ends being about half an inch distant from each other. If the tube be then filled with water, and a moderate charge be conducted through it, the tube will certainly be broken, and that in spite of its thickness.

Allusion has already been made to the expansion of air by the transmission of electricity, and all other gases are affected in a similar manner. This can easily be shown by Kinnersley's electric air thermometer.

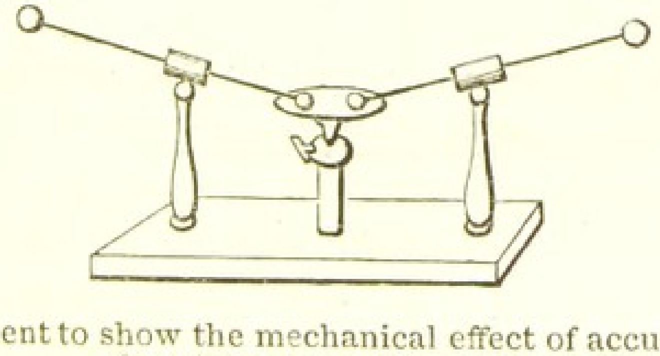
"The expansion of fluids by electricity," says Mr. Singer, "is, indeed, very remarkable, and productive of some singular results. When the charge is strong, no glass vessel can resist the sudden impulse. Beccaria inserted a drop of water between two wires in the centre of a solid glass ball of two inches in diameter; on passing a shock through the drop of water, the ball was shattered with great violence. Mr. Morgan succeeded, by the same means, in breaking green glass bottles filled with water, when the distance between the wires that conveyed the spark and the sides of the glass exceeded two inches."

The mechanical effect of electricity is not confined to the gases and liquids, though it is greater on them than on solids, as might be expected ; for the superior cohesion of the particles of the last mentioned must present a greater resistance to the electric agents than the former. If a discharge be made over dough, an indentation will be formed upon its surface marking the path of the electric agent. If over snow, the same appearance is presented. A few experiments will further illustrate the expansive power of the electric agent over solid substances.

Experiment 1. Place two wires in opposite parts of a piece of soft pipeclay, and pass a strong shock through them ; the clay will be curiously separated between the two points.

Experiment 2. Take a piece of thick plate glass, about an inch square, and place it upon the table of

Fig. 44.



Experiment to show the mechanical effect of accumulated electricity upon plate glass.

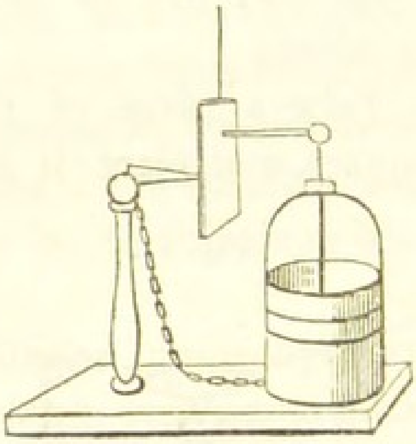
an universal discharger (fig. 44), and cause it to rest firmly on the table, by placing a weight upon it.

Let the points of the discharging wires be placed against the under edge of the glass, and opposite to each other. If the charge of a large jar be then transmitted through the wires, the glass seldom fails to be broken, which either arises from the sudden expansion of the air, or from the violence of the concussion.

Experiment 3. Insert two wires in a piece of wood, about half an inch long, and a quarter of an inch thick, so that their points may be about a quarter of an inch distant from each other. A strong charge passed through the wires will burst the wood asunder.

Experiment 4. Let a varnished card that has been coloured by vermilion, be insulated in such a position that it shall be between two blunt points (fig. 45). If

Fig. 45.



one of these be connected with the interior coating of a charged jar, and the other with the exterior, the electricity will pass from the point connected with the overcharged surface, to that which is connected with the undercharged surface, and a perforation is found at the point where the electricity entered the negative line of communication.

This last experiment has been urged in support of more than one theory, under the different modifications of which it is susceptible. Some have used it as a proof of the existence of one electric agent, and others of two, to which we shall presently advert.

From the experiments that have been mentioned, it may be deduced as a general law, that electricity produces violent mechanical effects upon bad conductors, and good conductors that are not of sufficient dimension to give it a ready passage. We consider the experiment of burning wires as an example of the latter. A large accumulation of electricity is obtained, the whole of which is to be instantaneously conducted away by an almost invisible wire: the rapidity of the passage, and the concussion which the particles suffer, raise their temperature, and fuse the wire.

The fracture of a thick glass tube containing water, ether, or any other indifferently conducting substance, by the discharge of a large jar through it, is an instance of the mechanical force of electricity opposing and overcoming the forces which resist the passage of the electric agent. We are, therefore, inclined to believe that the mechanical effects of ordinary electricity are to be traced to its successful opposition to all those forces which may, under any circumstances, attempt to resist its passage from one body to another, in its effort to establish electric equilibrium.

Although we have classed the principal phenomena produced by the action of electricity upon bodies, under the several heads to which they seem to belong, we are not certain that we have attributed them to their ultimate cause. The disengagement of heat may produce a chemical effect, and yet the heat may not be the immediate effect of the electricity, but only a result of mechanical force. There is an almost unconquerable difficulty in assigning to every phenomenon its origin; and we have only attempted, in the preceding remarks, to enumerate, under the several heads, the effects that are produced, without hoping to trace them to their origin. Nor can there be any expectation of accomplishing such a task till we have determined with certainty, of which there is no immediate prospect, the nature of electricity itself.

THEORIES OF ELECTRICITY.

The object of this little book being to explain the leading facts in the science of electricity, we have passed over many theoretical explanations which came in our way; but, however desirous we may have been to avoid allusion to theory, there are many advantages in adopting some definite and general notion of the agency which produces the phenomena to be explained. Theory also assists us to combine facts, and by a recurrence to the leading principle, we can always form an idea of the cause of a single appearance, which enables us not only to retain it in the memory, but also to associate it with facts which we before knew. Some purposes are therefore answered by a theory, even though it may not be absolutely true. But the value of a theory is determined by the amount of facts it is able to explain, and the facility with which it does so.

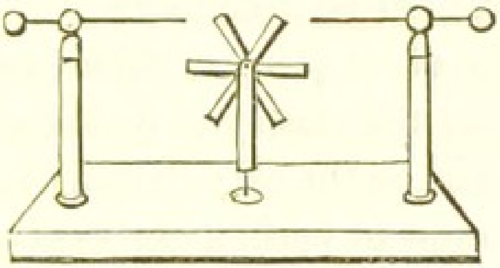
Two theories have been proposed for the explanation of electric phenomena. According to one, they derive their origin from the distribution and circulation of a subtle *fluid*, which pervades all substances; and, according to the other, from two *fluids*, which exist simultaneously in all substances. Both these theories may be developed by a few remarks, and the mention of those experiments which are thought by the advocates of each to support their particular views. Throughout this treatise, we have adopted the theory of a single agent, because of the simplicity which it introduces into all explanations, and from a belief that it will be found sufficient to explain every fact.

According to the theory of a single agent, electricity is a subtle fluid existing in a determined quantity, and in a certain degree of intensity, in all substances; and when in this state, they are said to be in their natural electric condition. But this state of equilibrium may be disturbed by friction, and the electricity, before latent, may be rendered free. Now it always happens, that when two substances are rubbed together, one obtains more than its natural quantity of electricity, that is, becomes positive, while the other has less, or is negative. Upon this supposition, one class of theorists explain all electrical phenomena, such as attraction and repulsion, transference and induction.

The form and place of the perforation formed in a card by the passage of an electric charge, is generally urged as a proof of the existence of but one agent. There are two experiments, however, which appear to bear stronger evidence in favour of this opinion, than the form and position of the burgh upon a card, or, what is more proper for the experiment, a piece of tin-foil.

Experiment 1. Take a light pasteboard float wheel (fig. 46), the vanes being fixed in a piece of cork, and

Fig. 46.

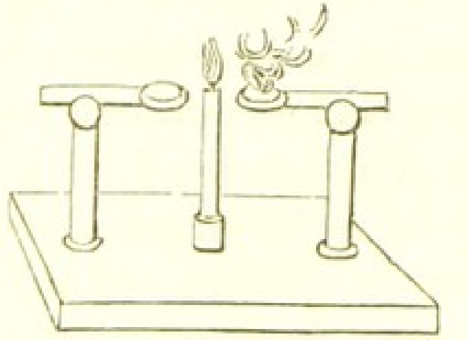


Experiment to show the direction of the electric fluid.

let it be so arranged that it may turn freely upon an axis. On each side place two pointed wires, and let one of these be connected with the positive, and the other with the negative conductor of the machine. As soon as the machine is put into action, the wheel will begin to revolve, and always in such a direction as would be occasioned by the passage of a fluid from the positive to the negative surface.

Experiment 2. Figure 47 represents a lighted taper, between two insulated brass cups, in each of which

Fig. 47.



Experiment to show the direction of the electric fluid.

is placed a small piece of phosphorus. If one of these be connected with the positive, and the other with the negative conductor, and the machine be then put into action, the flame will be always driven from the positive towards the negative side, and the phosphorus of the negative cup will be inflamed.

By one class of inquirers, these experiments are thought to favour the theory of a single electric agent. There is, however, on the other hand, another class, who believe that motion in both these experiments is to be traced to a repulsive power, communicated by the electricity to the particles of air situated in its path, and that the fundamental law of electric action, bodies charged with the same electricity repel each other, will account for the results observed in both instances. It cannot be denied, that this argument would, in a great measure, account for all the phenomena which depend upon the transference of electricity from a single point. But admitting this as applicable to one of the experiments, it may still be asked, how it is that the current is not produced by both points?

It will not be denied that two equal forces acting in opposite directions neutralise each other. From this it follows, that, if both points, in fig. 46, gave out a current of electricity, and electrified the particles of air in their vicinities, thus producing a current, the wheel ought to remain stationary. But as this is not the case, one of two other circumstances must exist; either the current from the positive side is greater than that from the negative, or the positive is the only point from which the electricity passes. This experiment, therefore, must in justice be given to the supporters of the theory that there is only one electric fluid.

Those who believe in two electric agents, give them the same properties as have been given by the other class of theorists to their single agent. These two agents are supposed to be contrary in their nature the one to the other, and yet they exist together in all substances, and neutralise one another. By friction they are excited, and one is always accumulated on the surface of the substance that is rubbed, and the other on the rubber. That kind which is accumulated on resinous substances, they call resinous electricity; that on glass and vitreous substances, vitreous electricity.

By this theory, the electric phenomena can no doubt be explained; but it not only fails in simplicity, but there is an apparent deviation from the plan that has been usually adopted by the Creator in his works,—the use of a complex machinery. This question has been often discussed, and with some ingenuity, on both sides; and an abstract of the arguments, with the application of the theories, will be found in any of the old treatises on Electricity; on this account it is the less necessary that we should deviate from our original plan, or touch the dirty waters of discord.

In what has been written, we have chiefly aimed at simplicity in the explanation of the fundamental facts of electricity; and by the introduction of experiment have endeavoured to give the student a taste for this mode of acquiring philosophical information; for, in order to readily acquire and retain a science, it must be learnt by experiment.

ATMOSPHERIC ELECTRICITY.

In the preceding pages we have endeavoured to give the reader a short and condensed account of the science of ordinary electricity. Through the work it has been our aim to explain facts in as few words as could be used; and in those instances where it was possible, to illustrate principles by experiment. In doing this, we may have deprived the book of all that interests a speculative reader, for it is probable that neither the style nor the matter may be such to attract as his attention. But, however humble may be the pretensions of the volume, it is hoped that it may be found a useful compendium of the most important principles of the science of ordinary electricity.

There is, however, one subject so intimately connected with the facts of which we have been speaking, that this volume could hardly be considered complete without a passing allusion. It may be asked by those who are unable to esteem any science that has not a direct application to the bodily safety or comfort of mankind,—of what use is your knowledge of the habits and condition of that mysterious agent you call electricity? The following remarks will answer that question.

The analogous appearances presented by lightning and electricity, when passing through a considerable space from one conductor to another, induced many electricians, particularly the Abbé Nollet, to suppose that there might be some connexion between the agents that produced them. These persons were satisfied with thinking; Franklin was not, but proved that which they only imagined. This celebrated man, in one of his papers upon electricity, brings together a number of the circumstances which seem to establish the analogy of the agents which produce lightning and the electric spark. Lightning is attracted by the highest bodies, and is most easily transferred by points; so is electricity. Lightning is most readily carried off by those bodies that are the best conductors of electricity. Lightning inflames combustible bodies, fuses the metals, changes polarity, and destroys life; and all these are the effects of electricity. The consideration of such analogies as these, could hardly fail to attract such a mind as Franklin's, and we accordingly find him resolved to remove all doubt by experiment. His first intention was to wait the erection of a spire which was in progress at Philadelphia, but his ardent mind, wearied with delay, devised a plan by which he could immediately solve the problem. The expedient he adopted was a simple one, and appeared in itself so childish that, for fear of ridicule, he determined to have no assistance but that which his son could give him. The apparatus that he employed to determine the nature of the analogy between electricity and the agent that produces thunder and lightning, was a kite, which differed in no particular from the toy used by children. Upon the approach of some dark clouds, he raised this simple apparatus into the air. For some time he observed no effects which could lead him to suppose that electricity was present, but the hempen threads were afterwards found to rise, as though electricity were passing from them. To avoid the passage of electricity through his person, he attached a silken cord to the hemp string, and by that he held the kite. At the point where the string terminated, he attached a key, by which he connected the instrument with batteries, or conductors, as he found necessary. At first, the effects were feeble, but as soon as the cord was wet by the fall of rain, abundance of electricity was found to be present.

In this way Franklin proved that electricity is the agent which produces thunder and lightning. After this he erected a pointed metallic rod in his own house, to the lower end of which he attached a moveable metallic knob, in such a way that when it was made to vibrate, it should strike against pieces of metal in the same manner as a common bell. When electricity passed through the rod, the knob was of course charged, positively or negatively, according to the electric state of the clouds. By the universal law of electric attraction, the knob was alternately drawn to and repelled by the pieces of metal, and thus a continued ringing was produced, which informed him of the presence of electricity.

The electrical kite is still used for the purpose of experimenting upon atmospheric electricity. In its general construction it does not differ from that used by

Franklin, but it is now generally made with a pointed wire, which extends a short distance above the top of the kite, and to this is attached the string, enclosing a fine wire, which being a good conductor, carries the electricity to the earth in large quantities. Great care is necessary in using this instrument, for the electricity is often so powerful as to render it unsafe to approach the string. The necessity for this attention will be best enforced by a relation of the unfortunate fate of Professor Richman. Franklin's brilliant discovery was soon known to the whole scientific world, and the attention of many philosophers was directed to the determination of all the effects of atmospheric electricity. Professor Richman, of St. Petersburgh, was one of these; and in order to facilitate his experiments, he had erected on the top of his house an iron conductor, to which he attached a chain, that was brought into his study. On the sixth of August, 1753, he was attending a meeting of the Academy of Sciences, but returned home, accompanied by a draughtsman, in consequence of the approach of a thunder storm. To the apparatus was attached an electrometer, which consisted of a linen thread, that traversed the face of a graduated quadrant. The thread had risen to about four degrees, and the Professor was explaining to his attendant the purpose of the electrometer, when a tremendous clap of thunder was heard, and he, stooping down to examine the state of the electrometer, received the electricity in his head, which instantly killed him.

The great importance of Franklin's discovery chiefly consists in the power which it gives us over the agent that produces thunder and lightning. It was once no uncommon thing to hear of buildings being struck by electricity, and of lives being lost. Franklin immediately perceived the importance of his discovery, and proposed the introduction of metal conductors as a security to buildings against the effects of atmospheric electricity. The only things to be attended to in erecting these are, that they should be raised a little above the highest part of the building, the upper end being pointed, and that they should be carried to some depth beneath the surface of the ground.

Electricity then is the cause of thunder and lightning, and it acts in the same way as when accumulated in a Leyden Jar. Thousands of acres of cloud are sometimes charged with electricity; and when we know what destructive effects may be produced by a few feet of electrified surface, as the discharge of a battery, we need not be surprised at the effects produced by violent thunder-storms.

It is now generally supposed by electricians, that the aurora borealis is an electrical phenomenon, and that the appearance arises from the passage of electricity in the higher regions of the atmosphere. This opinion seems to be justified by the circumstance that the phenomenon may be imitated by conducting the electric fluid through a tube partly exhausted of air, and by the effect it is known to have upon the magnetic needle.

Shooting stars are attributed to the passage of electricity in the furthest limits of our atmosphere, in the space between the region of the aurora borealis and the lightest clouds. This phenomenon is more frequently observed in the torrid zone than in other parts. It is recorded that they were seen by the inhabitants of Quito, above the volcano of Cayambo, in so great a number as to give the appearance of the mountain in flames. But the most remarkable instance of their appearance was observed at Mexico, by Humboldt and Bonpland. At this time thousands of shooting stars were observed; and it is stated by Bonpland, that not a space in the firmament equal to three diameters of the moon, was unoccupied by these meteors.

It is probable that many other atmospheric phenomena are attributable to the electric agent. How far its influence extends in the production of the phenomena we witness, and the state of things which now obtain in material creation, we do not expect to learn ; but from what we do know, we may deduce that it has been employed in establishing the present order of terrestrial affairs, and is necessary for the continuation of its existence.

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THE END.

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